The gradual release of responsibility: A case study of teaching science inquiry skills

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Abstract

Science education is valued in Australia and internationally for providing young people with the life skills to adapt to the challenges of a rapidly changing world as well as ensuring ongoing economic prosperity. Undoubtedly, scientists and science educators agree that science is a way of explaining the natural and material worlds whilst generating a sense of awe and wonder. An essential component of science education must include developing an understanding of scientific skills and concepts, as well as the ability to apply a scientific perspective and to think scientifically about evidence. Furthermore, the development of scientific literacy requires an individual to understand subject matter, the nature of science (NOS), and Scientific Inquiry (SI). However it is apparent from a growing body of research that the challenge faced by teachers is how to integrate these three areas. Furthermore, teachers have diverse understandings of the meaning and ways of planning, teaching and evaluating Scientific Inquiry. This study sets out to address these concerns through an investigation of a pedagogical approach referred to as the Gradual Release of Responsibility (GRR) model of instruction, which assists teachers to teach Scientific Inquiry Skills in a primary classroom (year-4, 9 year old students). Such research is necessary since there is little research on instructional models that structure teaching and learning for improved scientific literacy.

A single case (classroom) study approach was adopted to identify the teaching strategies, affordances and constraints of the GRR model and learning outcomes for students during the teaching period of eight lessons in a year-4 classroom. In alignment with case study design (Yin, 2009), rich and extensive data sources for the research were organised around three main foci:

1. Gradual release of responsibility framework;
2. The teacher;
3. The students.

A range of teacher data sources such as lesson planning documents, PowerPoint presentations, photographs, observations, the teacher's reflective

journal and informal interviews were collected. In seeking to identify what outcomes related to Science Inquiry Skills were achieved by students' data sources providing evidence of students' learning outcomes (e.g., PATScience assessments, pre-test of knowledge, observations including video and audio recordings of lessons, students' science journals and reflective journals, completed graphic organisers, post-teaching survey).

Through a scaffolded approach using the Gradual Release of Responsibility model of instruction, the year-4 teacher guided her students towards developing an understanding about Scientific Inquiry leading to the foundations of scientific literacy. Data were analysed using qualitative methods. In particular, a revised SOLO-taxonomy model was constructed for determining student achievement.

The findings revealed that a learning environment was established in which students engaged in rich conversations, designed and conducted experiments using fair testing procedures, made accurate observations and measurements, analysed and offered justifications for results, questioned the limitations of their ideas, and negotiated knowledge claims in ways similar to some of those in the scientific community. Significantly, analysis of teacher-student dialogue using a modified SOLO-taxonomy revealed that the teacher's scaffolding with questioning, prompting and cueing facilitated an increase in students' demonstration of deeper level relational responses. Also of significance was how students transferred what they had learnt in lessons into written work recorded in their science journals.

The GRR offered a flexible pedagogical approach for managing and modulating the information processing demands upon the teacher and learner. The teacher in this case study modulated her teaching by repeating the phases of the GRR more than once in the lesson sequence. Significantly, monitoring of students' science conceptual understanding and application of Science Inquiry Skills were warranted so the phases of the GRR could be adjusted to accommodate the needs of students in developing foundational scientific literacy.

The challenges teachers encounter when they attempt to integrate subject matter, NOS, and SI were addressed. The findings from this study suggest that through a modified GRR model of instruction teachers can structure the inquiry teaching experience to explicitly teach and scaffold students' learning of SIS while developing scientific understanding. Furthermore, the GRR model proposed by Fisher and Frey (2008) is modified to include a revised theoretical framework.

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Conference Papers

Whittaker, J.A. (2014, Oct). *Learning science inquiry skills through the Gradual Release of Responsibility.* Paper presented at the HDR student conference, QUT, Brisbane, Australia.

Whittaker, J.A., King, D., & Watters, J. (2015, July). *The gradual release of responsibility: A case study of teaching science inquiry skills*. Paper presented at the annual meeting of the Australasian Science Education Research Association, Perth, WA.

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

QUT Verified Signature

Signature:

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Chapter 1 **Introduction**

The value of science education in providing young people with the life skills to be able to adapt to the challenges of a rapidly changing world as well as ensuring ongoing economic prosperity is acknowledged in Australia and internationally (Aikenhead, Orpwood & Fensham, 2011; Zeyer & Kyburz-Graber, 2012). Undoubtedly, science offers insights into the natural and material world that generate a sense of awe and wonder. However, science opens the door to productive career pathways as those trained in science are recognised as innovative, valued and apt at critical thinking. However, it is apparent from a growing body of research that the current form of science education singularly fails to engage contemporary youth in advanced societies (Osborne, 2007b). Moreover, many developed countries, including Australia, are confronting low levels of scientific literacy among their populace. Of significance, is evidence that supports a view that science teaching in primary schools has a key role to play in shaping future views of students in regards to pursuing further study of science (Osborne, 2007a):

> If students were to engage with science in any significant way, then they must have sustained a positive experience of science from the beginning of elementary school. Once they lose interest the likelihood of re-engaging with science is low. (p.105)

Therefore, in response to concerns about science education raised by recent reports on students' achievements and interest in science (Office of the Chief Scientist, 2014), this study seeks to explore the development of an instructional model that will contribute to primary teachers having the capacity and confidence to implement sound, effectual and innovative instructional methods for teaching science. Specifically, the centrepiece of my research agenda is understanding and developing viable ways to support teachers and students in using and understanding Scientific Inquiry as an approach for developing scientific literacy. In alignment with case study design (Yin, 2009), rich and extensive data are presented.

This chapter begins with an overview of contemporary issues in science education (1.1) and an analysis of science education in Australia in comparison to other OECD countries (1.2). Subsequently, the aims of the study are elaborated (1.3) coupled with the rationale for this thesis (1.4). The chapter concludes with an overview of the thesis structure (1.5).

1.1 21st century education goals

The value of science education to Australia's prosperity is clearly recognised at a policy level in *The Melbourne Declaration of Educational Goals* (Barr, et al., 2008, p.4), "In the 21st century Australia's capacity to provide a high quality of life for all will depend on the ability to compete in the global economy on knowledge and innovation". The Declaration recognises the vital role schools play in preparing young people for the challenges of a changing world and ensuring the nation's ongoing economic prosperity: The rapidly changing nature of Australian jobs due to globalisation and technological advances demands that education and skill development prepares students for these new fields (Barr et al., 2008). The nature of jobs available to young Australians is evolving in direct response to globalisation and technological changes, thus placing greater demands on education and skill development in Australia.

1.1.1. Scientifically literate and engaged population

A recent national survey commissioned by the Australian Academy of Science, has found that the science literacy of young Australian adults has fallen in the last three years (Wyatt & Stolper, 2013). Put simply, Australia is failing to achieve the goal of a scientifically literate populace who can confidently participate in public debate about science, technology and environmental issues. However, a positive outcome of the survey identified high acknowledgement that science education is important to the Australian economy.

With the growth of occupations in the science and science-related fields accompanying the knowledge economy, it is more important than ever to achieve a scientifically literate and engaged population. Australia has traditionally relied on wealth production from resources and agriculture, but the creation of wealth is no longer exclusively related to resources and industrial processes (Aikenhead et al., 2011). Wealth is now a consequence of ever-renewing knowledges necessary to innovate, design, produce and market products and services.

Hence, the achievement of a scientifically literate and engaged populace is recognised as the key to global economic success. This thesis argues that science educators have a key role in our scientific and technological society and, as such, must be afforded professional development opportunities to learn how to implement instructional methods that help students to develop scientific literacy.

1.1.2. International perspectives

Australia is not unique among developed countries confronting low levels of scientific literacy among its populace. International education systems have acknowledged the importance of science education by implementing initiatives in order to address these concerns and provide young people with the life skills to be able to adapt to the challenges of a rapidly changing world. The *Science for All Americans: Project 2061* was founded in 1985 as a long-term initiative of the American Association for the Advancement of Science (AAAS) to help all Americans become literate in science, mathematics, and technology. Project 2061 (AAAS, 2013), through the development of *Science for All Americans*, *Benchmarks for Scientific Literacy* and the two-volume *Atlas of Science,* has provided a set of K-12 learning goals to serve as a foundation for state and national standards. Subsequently, a *Framework for K-12 Science Education* (National Research Council, 2012) was released and more recently, the National Academy of Sciences, the American Association for the Advancement of Science (AAAS), and the US National Science Teachers' Association have completed the two-step process to develop the *Next Generation Science Standards* (N.G.S.S. Lead States, 2013) to provide all American students an internationally-benchmarked science education.

Similarly, in the United Kingdom a report by Miller and Osborne (1998) identified the growing need to offer a more flexible science education for future scientists as well as a future consisting of scientifically literate citizens. The need for a compulsory science curriculum for the twenty first century is explained, “the rapid pace of technological change and the globalisation of the marketplace have resulted in a need for individuals who have a broad general education, good communication skills, adaptability and a commitment to lifelong learning” (Miller & Osborne, 1998, p. 1).

1.2 The state of science education in Australian schools

In addressing the call for more interest in science as a career choice for the future, it is necessary to ask the question, “Why are young people in schools and universities not acquiring the skills needed for our future prosperity?” Common themes have emerged in research that are significant in influencing the current state of science education in schools. An examination of how Australian students are performing is now presented.

1.2.1. Comparisons between Australian and international assessments

Internationally, there have been assessments that compare Australian students’ results on maths and science tests with other OECD countries. These international tests are the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMMS). Data from these international assessments are used to inform the progress of Australian school students towards achieving the *Educational Goals for Young Australians* as described in the Melbourne Declaration (Barr et al., 2008). Reports by the Australian Council for Education Research (ACER, 2006, 2009, 2012) have identified how Australia measures up to other countries on both PISA and TIMMS assessments. Analysis of these reports identifies worrying trends that have emerged in data from both assessments in recent years.

In the PISA 2012 scientific literacy assessment, Australia achieved an average score of 521 points, which was significantly higher than the OECD average of

501 score points. This result appears impressive on the surface; however, Australia was not one of the fourteen countries demonstrating a significant improvement in their performance between PISA 2006 and PISA 2012. In addition, Australia's 2012 PISA assessment of scientific literacy indicated that Australia's score for scientific literacy in 2012 was not significantly different to that in PISA 2009. This is despite the implementation of initiatives aimed specifically to raise the level of scientific literacy nationally. Details of these initiatives are discussed in Section 1.2.5. In 2006, the main focus of PISA was scientific literacy. Data from PISA 2006 identified that Australian students demonstrated a relative weakness in one scientific literacy competency in particular; *explaining phenomena scientifically.* In 2015 scientific literacy again will be the focus of PISA, and changes over time in scientific literacy will be able to be monitored.

In a report by ACER (2012) on the 2006 PISA results, positive correlation between being highly motivated to learn science for future study or career purposes and scientific literacy performance ($r = 0.29$) was revealed.   However, it is also important to note that the report identified a high percentage of Australian students (40%) who did not aspire to achieve a science-related career or complete further study in the area of science after secondary school and only 22% indicated they would like to work on science projects as an adult (Thomson, 2008). For Australian science educators and science teachers these results provide a reason to explore the educational implications of the declining proportion of students interested in pursuing science as a career choice.

ACER's Report (2012) on the results of TIMSS 2011 Science survey found that Australian year-4 students' scores declined significantly from TIMSS 2007. Students in 18 other countries outperformed Australian year-4 students. Australia's year-8 average score in science achievement was significantly lower than that of nine other countries. Thirty per cent of students in Australia did not reach the Intermediate international benchmark in science, the minimum proficient standard. The report also found that Year-8 students who like learning science had higher average science achievement than those who only *somewhat* or *do not like learning science*, which supports findings from PISA

2006 Science. Attitudes toward science and confidence doing science were identified as areas requiring attention. The majority of Year-8 students do not value science and less than half of year-4 and year-8 students are *confident* doing science. A relationship between confidence in doing science and achievement was acknowledged. On average, students who were *confident* with science had significantly higher average science scores than those who were not (Thomson, Hillman & Wernert, 2012).

In comparison to other OECD countries that have shown improved results, these results indicate that Australia is facing downward trends in both achievement and attitudes toward science that must be addressed. The alarming results indicate that Australia needs to address the lack of skills in scientific literacy to enable students to prepare for opportunities in Science, Technology, Engineering and Mathematics fields and face the challenges of the twenty first century.

1.2.2. Declining enrolments in science

While nations around the world agree that education in mathematics, science and technology is critical to a nation's future success, a growing concern in Australia has been the declining proportion of students enrolled in science subjects at the senior level of education. This worrying trend has continued in the past couple of decades. The Choosing Science study has attributed the significant declines in the proportions of high school students choosing senior physics, chemistry and biology courses in Australia to the more competitive curriculum environment, which makes it critical that steps are taken to ensure school science is more engaging, inclusive and valued by students (Lyons & Quinn, 2010).

A declining interest in science is impacting negatively on Australia's tertiary sector and workforce (Quintini, 2011). A report by the Australian Academy of Science (2012) commissioned by Australia's Chief Scientist, found that since 1991 the percentage of year 11 and 12 students enrolled in science subjects has fallen dramatically, from 94.1% to only 51.42% in 2010.

1.2.3. Lack of interest in science

Attitudes towards learning science and interest in science have important long-term implications for the broader economic, social and cultural growth. However, a study commissioned by the Office of the Chief Scientist and funded by the Australian Government has found that our failure to engage students in science in lower secondary school has resulted in a decrease in the number of students studying senior science (Goodrum, Druhan & Abbs, 2012). The results of the study revealed that almost three-quarters of Year 11 and 12 non-science students agree that science is important to Australia's future but few see science as relevant in their own everyday lives. The authors concluded, "For a country that believes its future prosperity depends on innovation and a skilled workforce, this situation needs to be addressed" (Goodrum et al., 2012, p. 57). Therefore as a matter of urgency, one of the recommendations of the study is to direct attention towards assisting teachers to improve the quality of science engagement.

In a review of literature, Osborne (2007) offers some compelling evidence to support a view that science teaching in primary schools has a key role to play in shaping future views of students in regards to pursuing further study of science. While student interest in science at age 10 has shown to be high and with little gender difference, research also suggests that the point of decline begins in the final years of primary school (Murphy & Beggs, 2005). "Moreover, a recent analysis of longitudinal data collected in the USA would suggest that, by the age of 14, students' interest in pursuing further study of science has been largely formed" (Osborne, 2007a, p. 105). Interest and attitudes are clearly important contributors to engagement, as Bybee, McCrae and Laurie (2009) have asserted:

> An important goal of science education is for students to develop interest in and support for scientific inquiry as well as to acquire and to subsequently apply scientific and technological knowledge for personal, social, and global benefit. That is, a person's scientific literacy includes certain attitudes, beliefs, and

motivational orientations that influence personal actions. (p. 869)

1.2.4. Perceived difficulty of science

There is a general agreement that many aspects of science are difficult to understand (Goodrum, et al., 2012). The aspects of science that are most challenging include the literacy demands of the science discipline, the mathematical components of physics and chemistry, the complex nature of concepts and the perceived lack of relationship between the science strands (Goodrum & Rennie, 2007; Webb, 2009; Yore, Pimm & Tuan, 2007). Although many school curricula have adopted the strategy of embedding real world contexts into the teaching of science with increased emphasis on understanding of its nature, there is disparity between the curricula and 'science as it is taught' (Osborne, 2007a; Osborne & Collins, 2001). In implementing science curricula, there is an overemphasis on learning a store of established scientific knowledge that is reflected in assessment tasks at the expense of equipping students to become scientifically literate citizens (Osborne, 2007b; Yore et al., 2007).

1.2.5. Australian initiatives

Reforms in Australian science education over the last decade have consistently identified the fundamental purpose of school science education is to promote scientific literacy. Helping our students to become scientifically literate means helping them to understand more about science and its processes and recognising the need for scientific literacy as a basic need for effective citizenship (Goodrum & Rennie, 2007).

Australia's National Action Plan 2008 – 2012 (Goodrum & Rennie, 2007) states concerns about the quality and status of science teaching and learning in Australian schools, which has provided a basis for determining further actions. These actions include: raising community awareness of science and science education; addressing issues about teacher supply and demand, improving initial teacher education, professional development and professional standards; increasing resources; improving assessment; and increasing national collaboration (Goodrum & Rennie, 2007). As a result of the national action plan, a number of initiatives such as Australian School Innovation in Science, Technology and Mathematics [ASISTM], Science by Doing, National Science Week, Science Spark and Primary Connections were enacted, with the fundamental purpose of promoting scientific literacy in schools. While Australia has recently taken further steps to adopt a nationally consistent approach to the teaching of science with the implementation of the Australian Curriculum (ACARA, 2012) as well the Australian Academy of Science program, Primary Connections (Australian Academy of Science, 2012) still the decline in the proportion of students enrolled in science subjects continues. A correlation between the decline in scientific literacy of young Australians and enrolments in science subjects can be inferred from this evidence.

In spite of being strongly promoted as a goal of science education (Goodrum & Rennie, 2007; National Research Council, 2012), developing the competencies of scientific literacy is continuing to be a highly problematic issue in science education today. The challenge for Australian educators is to act on these findings, as other countries have, to lift educational outcomes for all students. Given there is a correlation between achievement in science and confidence in science, liking science and valuing science, it is pertinent to pursue a model of teaching that monitors and improves students' attitudes towards science and confidence in learning science.

1.3 Interdisciplinary research

To address this problem, there is an emerging, broad consensus within the science education research community about the need to characterise and explain current or possible future effective classroom practices that promote, or could promote the literacies of science, including the language practices of science discourse and its processes, for example, investigating, reading, writing, speaking, critical thinking and reasoning (Linder, Östman & Wickman, 2007; Norris & Phillips, 2003; Yore et al., 2004). In seeking to identify evidence-based approaches to effective teaching and learning practices in science literacy, a growing body of research published in science teaching journals in the last decade has cited research from literacy education more often than from science education (Hand, Yore, Jagger & Prain, 2010). This clearly has implications for the science education research agenda and demonstrates support for research that draws on successful practices promoting interdisciplinary learning.

Science literacy is not about teaching another subject, and it should not be considered just an add-on to science. It's about making sure that students understand and apply what they are taught. In considering the question of how students develop new understandings or meanings in science classrooms as well as the ability to communicate what they have learnt to others, the role of the teacher is central. According to the Vygotskian (1978) perspective the teacher mediates and passes on existing scientific knowledge as well as the processes of science to students. Bruner (1985) also supports the notion that without the aid and assistance of others, mastery of the conceptually organised rules and belief systems of science could not be achieved. Furthermore, Wood, Bruner and Ross (1976) established that the teacher has a key role to play in scaffolding students to solve a problem, carry out a task or achieve a goal which would be beyond the learner's capability alone. The Vygotskian sociocultural theory taken together with the work on scaffolded instruction (Wood et al., 1976) underpin a model of instruction, the Gradual Release of Responsibility (GRR), which is central to this research for teaching Science Inquiry Skills.

This study draws on the GRR, which was first introduced by Pearson and Gallagher in 1983, for teaching reading comprehension skills to students. Fisher and Frey (2008) have subsequently evaluated the four instructional phases of the GRR in the last decade. The GRR allows for instruction that moves from explicit modelling and instruction to guided practice and then to tasks that slowly permit students to become independent learners. This model has been proven successful for teaching literacy, thus it is reasonable to assume that it could also provide a viable way for guiding students in a primary classroom to develop scientific literacy.

1.4 Aims of this study

Primary teachers have a key role in our scientific and technological society as science communicators and educators who lay the foundations to position students as active learners of science through inquiry based approaches. Specifically, primary science teachers require the confidence and skills to implement sound, effectual and innovative instructional methods for engaging students in sustained positive learning experiences so as to develop in students an interest in and positive attitude towards learning science.

As a result of the educational experiences designed by primary teachers, students should develop an understanding of the basic elements that underlie science as a way of knowing and explaining the natural world (Bybee, 2004). Furthermore, students should develop some cognitive and metacognitive abilities and Scientific Inquiry Skills (SIS) including strategies for questioning, discussing, reading and writing, evaluating scientific arguments and reasoning scientifically while engaged in processes of Scientific Inquiry (Yore et al., 2007). Such scientific inquiry skills are necessary for improved scientific literacy; however, teachers require a good knowledge of research based instructional procedures that are proven to be effective in order to teach such skills to students.

A body of research (Rosenshin & Stevens, 1986) identified instructional procedures that influence student learning outcomes. Two findings from their research identified instructional procedures that are most relevant for teaching. These included (1) the importance of teaching in small steps (2) the importance of guiding student practice. Subsequently, Adams and Engelmann (1996) developed an approach to direct instruction that included identifying performance goals and success criteria for expected learning, optimising student engagement, explicitly teaching overarching ideas, breaking down the skills being taught into a planned sequence of lessons and embedding continuous assessment and feedback. More recently Hattie (2009), in his study on Visible Learning, identified direct instruction among the more successful programs in promoting learning. In other words, the notion of scaffolding students' learning with support provided by purposefully designed learning experiences that provide just the right amount of support to guide the child or a novice step-by-step to solve a problem, carry out a task or achieve a goal that he or she would not be able to achieve on his or her own, can potentially provide a way to influence student outcomes. Direct instruction in this thesis is situated in a sociocultural perspective where students are still active learners through their cognitive and social engagement.

As the GRR model provides a detailed teaching process for how students can learn to use the transferred skills independently with the guidance of an adult; this current study was performed on the basis of this model for teaching aspects of scientific literacy including questioning, observing, measuring, fair testing processes, recording and analysing data and communicating. This model of instruction proposes that the cognitive load should shift slowly and purposefully from teacher-as-model, to joint responsibility, to independent practice and application by the learner. In this model, the teacher transfers responsibility for performing a task gradually to students over a period of time (Fisher & Frey, 2008, 2014).

Therefore, in response to concerns about science education raised by recent reports on students' achievements in science (Section 1.2), this study investigates how a primary science teacher implements the GRR model for teaching Science Inquiry Skills (SIS) to primary school students who are new to the discipline of science and guide them towards developing an understanding about Scientific Inquiry leading to the foundations of scientific literacy.

Additionally, this study aims to explore how the GRR model, which is discussed in greater detail in Section 2.3, can provide a pedagogical framework for teaching Scientific Inquiry (SI). In particular, it seeks to document how a teacher can scaffold students in the asking, investigating and answering of their own scientific research questions. Consequently, this thesis argues that the GRR model of instruction could allow teachers to play an active role in scaffolding all students to develop any number of skills, including Scientific Inquiry Skills. The aim of this study is to answer the overarching question, "How does the teacher implement the GRR model of instruction to teach Scientific Inquiry Skills (SIS) in the classroom?" To address this aim I pose three research questions:

1. What strategies does the teacher use to implement Science Inquiry through GRR practices in a year- 4 Science class?
2. What affordances/constraints does the teacher identify in using these

strategies?

3. What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model?

1.5 Significance of the study

This section presents the rationale for the thesis. It elaborates the foci of the study, specifically how instructional model will address the declining participation and interest in science by positioning primary teachers to engage students in positive learning experiences by implementing an instructional model, namely the GRR, for teaching Science Inquiry.

This study's contribution to the field of science education is significant from the perspectives of both teacher education and teaching Scientific Inquiry. This thesis builds on previous research (Ireland, Watters, Brownlee & Lupton, 2012) by investigating how a primary teacher structured the classroom learning environment to scaffold student Scientific Inquiry. Ireland et al. (2012) propose:

> Pedagogical practices that hope to achieve the greatest outcomes for students through inquiry teaching should look beyond motivating students through interesting experiences, and beyond challenging them with teacher generated problems, to actually scaffolding students in the asking and answering their own questions. (p. 173)

Thus, this study responds to this recommendation by investigating an instructional model in which the teacher's role is to guide and structure the inquiry teaching experience to encourage, value and scaffold students' questions through teacher-student dialogue. In doing so, over time students may learn to answer and generate questions at many levels of complexity.

Pearson and Gallagher's (1983) GRR model of instruction has been applied to students' language learning for over 30 years (Clark & Graves, 2005; Lin & Cheng, 2010a; Pearson & Gallagher, 1983), but also has potential for teaching science, more specifically Scientific Inquiry. Indeed, while curricula have identified the fundamental abilities and concepts that underlie Scientific Inquiry and much has been written in support of its role as an integral component of scientific literacy (Bybee, 2004; DeBoer, 2004; Venville & Dawson, 2004), many elementary teachers continue to struggle with conceptualising the meaning of Scientific Inquiry as well as ways to structure science teaching so it accommodates the goals of developing the abilities and understandings of Scientific Inquiry. In this study, the term Scientific Inquiry (SI) will be used to refer to the general processes of science investigation that scientists use as they attempt to answer questions about the natural world (Bybee, 2004). Consequently, Science Inquiry Skills (SIS) important for learning include strategies for discussing, reading and writing, evaluating scientific arguments and reasoning scientifically while engaged in processes of Scientific Inquiry. In addition, it is argued that students' ability to learn Science Inquiry Skills is directly influenced by how they are taught, which is the focus of this study. Therefore, the centrepiece of my research agenda is understanding and developing viable ways to support teachers and students in using and understanding Scientific Inquiry as an approach to developing scientific literacy.

1.6 Position of the researcher

The GRR model of instruction differentiates this study from other science education studies. The GRR, developed by Pearson and Gallagher (1983), proposes that the cognitive load should shift slowly and purposefully from teacher-as-model, to joint responsibility, to independent practice and application by the learner. In the collaborative learning phase of instruction students scaffold each other's learning when emphasis is placed on the role of peer-peer interaction, language and discourse in the development of understanding (Vygotsky, 1978). While there has been some research into the ways of organising classrooms so as to reflect particular forms of collaborative inquiry that can support students in gradually mastering the norms and practices that are deemed to be characteristic of scientific communities (Gillies, Nichols, & Burgh, 2011; Hackling, Peers & Vaughan, 2007), there has been no research using the GRR model of instruction for teaching Scientific Inquiry.

Working as a primary teacher for 30 years has provided me with a wealth of experience in the classroom and beyond the classroom: developing science curricula support resources; leading professional development for teachers; organising science conferences as a committee member of the Science Teachers' Association of Queensland (STAQ); Science is Primary Conference (2011-13); and coaching teachers in numeracy, literacy and science. This study can be seen as a culmination of my recent experiences planning and implementing inquiry- based resources and activities for teachers designed to further their professional development. Initially, my interest in leading professional development for primary science teachers was aimed at addressing a lack of confidence in teaching science expressed by many teachers in my school district. By gaining a federally funded grant to implement an Australian Schools Innovation in Science, Maths and Technology (ASISTM) Project, I could provide professional development in teaching Scientific Inquiry, in the form of a mentoring program, for 16 primary teachers from three different schools. Anecdotal data from the project, Hands-on for inquiry minds, showed positive effects on teachers' beliefs that their teaching can influence student learning. Subsequently, in the role as an eCurriculum Science writer for The Learning Place (Queensland Department of Education and Training), I commenced the development of filmed modelled lessons demonstrating how to teach Scientific Inquiry Skills. In response to the release of the new Australian Science Curriculum, the modelled lessons were designed for the purpose of professional development. Unfortunately, as sometimes happens with government projects, lack of funding prevented the completion of the filming. This has provided the impetus for my current research at the school where I teach, on supporting teachers to implement Scientific Inquiry Skills. Consequently, this study seeks to provide a revised theoretical framework for the implementation of the GRR model of instruction that will afford primary teachers the capacity and confidence to implement inquiry oriented science for improved scientific literacy.

1.7 Structure of the thesis

Chapter 1 has provided an overview of contemporary issues in science education coupled with a justification for this study. The research problem, aim and significance of this study were presented.

This thesis will investigate how a year-4 teacher implements Scientific Inquiry (SI) for improved learning outcomes in the classroom by answering three research questions:

1. What strategies does the teacher use to implement Science Inquiry through GRR practices in a year-4 Science class?
2. What affordances/constraints does the teacher identify in using these strategies?
3. What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model?

In order to address these questions, Chapter 2 will review relevant literature. While scientific literacy is identified as an overarching goal of science education, SI clearly emerges from the literature as an important aspect of scientific literacy. Therefore, conceptualisation of the meaning of SI and its implications for teaching in the primary school are explored.

Chapter 3 describes and justifies the selection of case study research as the appropriate research approach for this study. The chapter provides details of how the research will be managed including: the research design and case study perspectives; participants and role of the researcher; data generation, transcription and analytical tools; and the analytical framework relating the data to the theoretical framework of the thesis.

The results are presented and analysed in Chapter 4. In Chapter 5, a discussion of the results is presented, including identification of a revised framework for the GRR for teaching Science Inquiry Skills. Chapter 6 identifies topics for further investigation relating to the teacher's use of formative assessment and of the nature of teacher-student discourse in developing students' science reasoning ability.

Chapter 2 **Literature Review**

The purpose of this thesis is to address the questions:

1. What strategies does the teacher use to implement GRR practices in a year-4 Science class?
2. What constraints/affordances does the teacher identify?
3. What outcomes related to Science Inquiry Skills do students achieve?

In order to address these questions, the following chapter will explore the theoretical literature that support this study of teacher practice.

First in Section 2.1, scientific literacy as an overarching goal of science education is discussed and analysed followed by a review of the definitions of scientific literacy distilled from the literature. The four main themes of scientific literacy distilled from the literature are discussed, in order to unveil the significance of Scientific Inquiry (SI) as an integral component of scientific literacy. Second (Section 2.2), conceptualisation of the meaning of Scientific Inquiry (SI) is synthesised from the literature. This section includes a discussion of research on SI that identifies interrelationships between the various instructional approaches for teaching SI and their impact on students' inquiry and investigation skills in different contexts. Third (Section 2.3), an analysis of instructional design models, including minimally guided instruction and direct instruction, and their relationship to the GRR model of instruction developed by Pearson and Gallagher (1983) are explored as part of the justification for the study. The chapter is concluded (Section 2.4) with a summary of the major themes of the literature review and rationale for using the GRR for teaching Scientific Inquiry.

2.1 Scientific literacy

The proposition central to this study is that teachers have varying conceptions of inquiry teaching (Ireland et al., 2012) which has implications for both the enactment of inquiry oriented science teaching in the classroom as well as the uptake of new instructional models that enhance outcomes for engaging students in Science and lay the foundations for a scientifically literate populace.

A vision of achieving scientific literacy for all in the 21st century is a broad goal of science education that is generally reflected in curriculum documents as statements of learning and standards to achieve. Although educational objectives promoting scientific literacy as a goal for learning can be found in science curricula (the intended curriculum), whether or not a large proportion of students achieve them is almost entirely dependent on teachers and the effectiveness of their pedagogical practices (the enacted curriculum). A valuable first step is to synthesise a basic understanding of the term 'scientific literacy' from the literature. As the literature reviewed in this section suggests there have been multiple attempts to unpack the meaning of scientific literacy.

The *National Science Education Standards* (1996, ix) present a vision of a scientifically literate populace whereby people are able to:

- use scientific information to make choices that arise every day;
- engage intelligently in public discourse and debate about important issues that involve science and technology;
- share in the excitement and personal fulfilment that can come from understanding and learning about the natural world;
- share in the richness and excitement of comprehending the natural world;
- use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society;
- develop the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively.

This definition of scientific literacy, articulated by the National Science Education Standards for the United States, was criticised for being too broad and including virtually all of the objectives of science education that have been identified over the years (DeBoer, 2000). Furthermore, DeBoer recommended that clearly defined content standards are required for individuals to achieve these ambitious goals. Thus, in the United States the National Academy of Sciences, the AAAS, and the National Science Teachers' Association (2013) have subsequently completed a two-step process to develop the Next

Generation Science Standards (NGSS) to provide all American students an internationally-benchmarked science education. The NGSS (2013) are built upon The National Research Council's (NRC) Framework that describes a vision of what it means to learn science: “Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more” (p. 286).

The development of the United States NGSS has implications for Australian science education. To keep pace in a global society it is necessary for science teachers in Australia to be aware of how education systems in other OECD countries, such as the United States, are developing curricula and investing in practices for creating a scientifically literate populace.

The next section reviews key literature regarding scientific literacy, followed by a synthesis of the common themes and definitions to provide a basis for identifying aspects of scientific literacy relevant to Scientific Inquiry.

2.1.1. Visions of scientific literacy

Roberts (2007) proposes two schools of thought for generating conceptions of scientific literacy appropriate for school science.

- Vision I looks inward at science itself – its products such as laws and theories, and its processes such as questioning, hypothesising and experimenting. According to this vision, goals for school science should be based on the knowledge and skill sets that enable students to approach and think about situations as would a professional scientist.
- Vision II, on the other hand, looks outward at situations in which science has a role, such as decision-making about socio-scientific issues. In Vision II thinking, goals for school science should be based on the knowledge and skill sets that enable students to approach and think about situations as a citizen well informed *about* science.

The two visions have challenged the science education community to examine how curriculum documents and pedagogical practices reflecting the dual purposes of science education; educating for future scientists (Vision I) versus educating for future citizens (Vision II) are structured. For example, the Australian School Science Education National Action Plan 2008 – 2012, (Goodrum & Rennie, 2007) reflects Roberts' Vision II.

2.1.2. Scientific literacy for the 21st century

Osborne (2007b) proposes a vision of science education for the twenty first century, reflecting Robert's Vision II, that explicitly addresses science for citizenship in the belief that all students will benefit from a broad education about science. Students can then choose to do additional further science courses. Osborne espouses a view of scientific literacy that consists of four elements, namely, the conceptual and cognitive, ideas about science, and the social and affective aspects (Osborne, 2007):

> The conceptual which builds students' understanding of the knowledge and ideas of science; the cognitive which attempts to develop students' ability to reason critically in a scientific manner; 'ideas-about-science' which is an attempt to develop students' understanding of both the epistemic – how we know what we know – and the processes, values and implications of scientific knowledge; and the social and affective which attempts to develop students' ability to work collaboratively and to offer an engaging and stimulating experience. (p. 177)

Faced with the diverse needs and capabilities of students, the challenge is how to differentiate the teaching of science, whilst developing the competencies of scientific literacy for use in varied contexts and for worthwhile purposes in a socially responsible way. Overriding all this is the question of how to communicate science and its benefits to encourage greater awareness of the value of scientific knowledge and facilitate willing engagement with contemporary scientific issues.

2.1.3. Australian definition of scientific literacy

Given that this study is to be conducted in an Australian school, the emphases adopted in the Australian curriculum are important to understand. In the Australian School Science Education National Action Plan 2008 – 2012, Goodrum and Rennie (2007) reflect Roberts' Vision II in their definition of scientific literacy by describing scientifically literate people as:

> interested in and understand the world around them, engage in the discourses of and about science, are sceptical and questioning of claims made by others about scientific matters, are able to identify questions, investigate, and draw evidence-based conclusions, and make informed decisions about the environment and their own health and well- being. (p. 3)

An analysis of how scientific literacy is articulated in the Australian Curriculum (2015) reveals that it includes the scientific processes of science such as hypothesising and experimenting, as described in Robert's Vision I, but also requires the user to combine these skills with scientific reasoning and critical thinking to develop scientific knowledge and an understanding of the nature of science in real world contexts articulated in Robert's Vision II. Such real world contexts have been a central feature of the OECD's PISA assessment of scientific literacy. The next step for science educators and science teachers is to research teaching practices that develop these interrelated aspects of scientific literacy to address the Australian Curriculum requirements.

2.1.4. PISA definition of scientific literacy

The failure of science education systems in many developed countries to contribute to the wellbeing of science in contemporary society as well as the declining interest in science has led to recommendations for a humanistic perspective in school science emphasising real world contexts (Fensham, 2009). The OECD's PISA assessments focus on measuring performance in language literacy, numeracy and scientific literacy. PISA 2006 Science represents an assessment emphasising Robert's Vision II, which highlights the importance of educating future citizens who are well prepared in Science (along with Reading and Mathematics) for life in the 21st century (Fensham, 2009). The OECD created the Program for International Student Assessment (PISA) in Science to monitor the scientific competencies that clarify what 15-year-old students should know and be able to do within appropriate personal, social, and global contexts.

PISA 2006 defines scientific literacy in terms of an individual's:

- willingness to engage in science-related issues, with the ideas of science, as a constructive, concerned, and reflective citizen;
- scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, to draw evidence-based conclusions about science-related issues;
- understanding of the characteristic features of science as a form of human knowledge and enquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environment.

Scientific literacy requires an understanding of scientific concepts, as well as the ability to apply a scientific perspective and to think scientifically about evidence (OECD, 2007, p. 21).

PISA 2006 measured the *scientific competencies* defined as being important for 15-year-olds as they encounter, interpret, solve and make decisions in life situations involving science and technology:

- Identifying scientific issues
- Explaining phenomena scientifically
- Using scientific evidence (OECD, 2007, p. 21).

These three scientific competencies were selected by the OECD (2007), because of their relationship to scientific practices and abilities necessary for the development of scientific literacy. Some of these key abilities are inductive and deductive reasoning, critical evaluation of data for the construction of arguments and explanations, thinking, modelling and analysing in terms of systems, and using mathematics and technology. Features of the three competencies are described in Table 2.1.

Table 2.1

PISA 2006 scientific competencies

Identifying scientific issues
Recognising issues that can be explored scientifically
Recognising the key features of a scientific investigation
Explaining phenomena scientifically
Applying knowledge of science in a given situation
Describing or interpreting phenomena scientifically and predicting changes
Using scientific evidence
Interpreting scientific evidence and making and communicating conclusions
Identifying the assumptions, evidence and reasoning underpinning conclusions
Reflecting on the societal implications of science and technological developments

Source: Organisation for Economic Co-operation and Development (2007)

In defining these competencies, PISA 2006 provides a sound starting point for further research into the teaching and assessment of scientific competencies in other year levels. It was proposed by Fensham (2007) that "research into the teaching of scientific competences (discourses) may, indeed, bridge Douglas Roberts' two visions of Scientific Literacy" (Fensham, 2007, p. 113).

The next task for science education research, in close conjunction with teachers and students in real classrooms, is to extend our understanding of appropriate scientific competences for each stage or level of schooling, and to find how contexts, content and pedagogies will make them learnable by large numbers of students (Fensham, 2007). A pedagogical framework proposing how contexts, content and pedagogies, will make aspects of scientific literacy learnable by large numbers of students in the primary classroom is outlined in Section 2.2.

2.1.5. Fundamental and derived sense of scientific literacy

Vygotsky's (1978) social constructivist perspective that scientific knowledge is socially constructed in the classroom, influenced by existing ideas and internally validated and communicated has important implications for pedagogical practices. Students learn spontaneous concepts (e.g., what a flower is) from their everyday experiences and social interactions, however, abstract scientific concepts (e.g., what gravity is) are often invisible and abstract in nature. Science has distinct epistemologically empirical approaches, that is, how scientists come to know things. In science this includes developing an understanding of the facts, principles, laws, and theories of science as well as its processes (e.g., investigating, reading, writing, speaking, critical thinking and reasoning), and their philosophical underpinning. The social language or discourse of science that has been developed within the scientific community is quite distinct from that of other learning areas taught in schools, such as geography or mathematics. As Kelly (2011) argues, “Science has unique discourse features and these features are difficult for students to ascertain” (p. 69).

An emerging research agenda focuses on the importance of the “literacy component” of scientific literacy. Norris and Phillips (2003) promote a view of scientific literacy that comprise both the concepts, skills, understandings, and values generalisable to all reading and knowledge of the substantive content of science. They refer to the two interacting components of scientific literacy as the fundamental sense – being literate in the discourses of the discipline – and the derived sense – being knowledgeable in the content of the discipline. They propose that:

> A conception of scientific literacy that attended to its fundamental as well as to its derived sense would address the anomalous and destructive view that scientific knowledgability can be had by acquiring isolated bits and pieces of scientific information while acquiring no idea of how they are to be interpreted or interconnected. (p. 69)

Norris and Phillips argue that scientific literacy must be grounded in the fundamental sense of literacy. They refer to a claim by Anderson (1999) that “reading and writing are the mechanisms through which scientists accomplish [their] task. Scientists create, share, and negotiate the meanings of inscriptions – notes, reports, tables, graphs, drawing, diagrams” (p. 973). Norris and Phillips (2003) suggest there is a synergy between the fundamental (being fluent in the language, discourse conventions, and communication systems of science) and derived (being knowledgeable, learned, and educated in science) senses of science literacy.

The notion that becoming scientifically literate without acquiring literacy in its fundamental sense is further explored by Yore (2012):

> Research demonstrates that neither reading about science nor hands-on-science with no reading or writing is a sufficient method for effective conceptual learning. Writing about science creates opportunities to propose, reinforce, and revise conceptual knowledge. Integrating science, writing, and reading through authentic inquiry allows for a more engaging, purposeful, reflective, efficient, and effective approach, which improves reading comprehension, conceptual understanding, and academic writing. (p. 14)

An interpretation of Norris and Phillips' (2003) categories can be found in the work of Yore, Pimm and Tuan (2007). In consideration of the interactive roles of language, learning, and understanding, Yore et al. (2007) interpret Norris and Phillips' categories by articulating the cognitive relationship between the fundamental sense and the derived sense (Table 2.2).

Table 2.2

Interacting senses of scientific literacy – cognitive relationship

Fundamental sense	Derived sense
Cognitive and metacognitive abilities Critical thinking/ plausible reasoning Scientific language arts (reading, writing, speaking, listening, viewing, and representing in science) Information communication technologies (ICT)	Understanding the big ideas and unifying concepts of science Nature of science Scientific inquiry Technological design Relationships among science, technology, society, and environment (STSE)

This synergy has prompted further research into language and science literacy. It has been proposed that central components of the fundamental sense of scientific literacy and their use may enhance the derived sense of scientific literacy as well improve students' cognitive processing and understanding (Kelly, 2011; Klein, 2006; Webb, 2009; Yore, 2012; Yore et al., 2004).

Research into the synergy between the fundamental sense of scientific literacy and derived sense of literacy has been influential in drawing attention to the importance of language in science learning. It has been claimed that “Current worldwide science education reforms promoting science literacy for all students have encouraged many science educators to revisit the importance of language in doing science and learning science” (Yore, Florence, Pearson & Weaver, 2006, p. 111).

In a case study of two scientists’ beliefs and use of language in their particular discipline of science, the important role of metacognition in constructing and communicating science knowledge is highlighted. The transition between science and discourse domains and the resolution of evidence, argument, and linguistic problems are guided by their metacognition— awareness and executive control of science writing, scientific argumentation, and science inquiry. The scientists need to convert their metacognitive awareness into action to improve self-regulation (planning and generating ideas, translating ideas into text, checking and revising text) and actual writing. Three broad considerations of inter-related ideas are involved: writing heuristics, management of processes, and social nature of writing. Managing the writing is focused on three metacognitive processes: planning, translating, and revising (Yore et al., 2006, p. 117).

Yore recommends that “science instruction needs to illustrate reading and writing as interactive, constructive meaning-making processes; address metacognition as awareness and executive control of meaning making; and provide explicit strategy instruction on a just-in-time basis within authentic science inquiries and professional practices” (Yore, 2000, p. 105). It is therefore important to go beyond the traditional interpretation of reading and writing as tools of “communication” and consider how reading and writing can facilitate “knowledge production” and “conceptual learning” to improve scientific literacy.

The value of achieving a scientific literate populace is indisputable, but the question of how this can best be achieved is unclear. One approach may be to introduce an instructional model for teaching science inquiry in which the teacher’s central role is to position the students as active learners of science.

2.1.6. Synthesis of scientific literacy literature

In seeking to understand what competencies of scientific literacy are important to learn, a synthesis of current literature (Table 2.3) aims to identify common themes among the definitions of scientific literacy. No one model or vision of scientific literacy may suit the purposes and perspectives of science educators from elementary, secondary and tertiary education communities. However, it is proposed that identifying consistent themes within these models will help support cohesion and a clear approach to improving scientific literacy.

This *Synthesis of Scientific Literature* (Table 2.3), while not inclusive of all definitions, identifies common themes that have emerged from the literature discussed. The main themes of scientific literacy can be grouped into four categories, which are explained in the left-hand column and are discussed subsequently.

Table 2.3

Synthesis of Scientific Literacy Literature

Themes within literature		PISA (2006)	Roberts Vision I & II (2007)	Goodrum & Rennie (2007)	Osborne (2007)	Norris & Phillips (2003)	Yore, Pimm and Tuan (2007)
Metacognitive Thinking	Factual and conceptual knowledge of science	scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, to draw evidence-based conclusions about science-related issues and;	thorough knowledgeability and skill sets that enable students to approach and think about situations as a professional scientist would (Vision I) understanding science itself – its products such as laws and theories, and;		the conceptual process which builds students' understanding of the knowledge and ideas of science	being knowledgeable, learned, and educated in the content and discipline of science	understanding the big ideas and unifying concepts of science cognitive thinking

	Scientific Inquiry	Understanding of the characteristic features of science as a form of human knowledge and enquiry	its processes such as hypothesising and experimenting (Vision I)	engage in the discourses of and about science are sceptical and questioning of claims made by others about scientific matters are able to identify questions, investigate, and draw evidence-based conclusions	'ideas-about-science' which is an attempt to develop students' understanding of both the epistemic – how we know what we know – the processes and;	being fluent in the language, discourse conventions, and communication systems of science; possessing the interpretive strategies needed to cope with science text	scientific inquiry scientific language arts (reading, writing, speaking, listening, viewing, and representing in science) information communication technologies (ICT)

	Attitudes Towards Science	Interest in science	willingness to engage in science-related issues, with the ideas of science, as a constructive, concerned, and reflective citizen		interested in and understand the world around them	values and implications of scientific knowledge		

		Informed responsible decision-making about socio-scientific issues	awareness of how science and technology shape our material, intellectual, and cultural environments	thorough knowledgeability about situations in which science has a role, such as decision-making about socio-scientific issues (Vision II) knowledge and skill sets that enable students to approach and think about situations as a citizen well informed *about* science (Vision II)	make informed decisions about the environment and their own health and well-being	the social and affective which attempts to develop students' ability to work collaboratively and to offer an engaging and stimulating experience		nature of science technological design relationships among science, technology, society, and environment (STSE)

The four categories include:

1. Factual and conceptual knowledge of science

Knowledge of the terminology of science is important to learn including conceptual knowledge of classifications and categories, structures, models, theories and systems required to explain and predict phenomena, apply understandings in new situations and make the important connections to the larger system of scientific ideas.

2. Scientific Inquiry

The definition of “Scientific Inquiry” which is distilled from the synthesis of scientific literacy is defined as an understanding of the inquiry processes such as hypothesising and experimenting, how to communicate scientifically with written and spoken communication and by using ICT, and how to analyse and debate socio-scientific concepts and issues in social contexts. In short, Scientific Inquiry Skills (SIS) important for learning include strategies for discussing, reading and writing, evaluating scientific arguments, and reasoning scientifically while engaged in processes of SI (questioning, investigating, observing, measuring, analysing data, communicating findings).

3. Attitudes about and towards science

Attitudinal and motivational factors influence science-related thinking, values, emotions, and actions. Two focus areas emerged within this theme: attitudes towards science and attitudes about socio-scientific issues. While relationships exist between the two areas, they are discussed separately.

a. Attitudes about science

In learning science it is important for students to develop knowledge of the social and cultural practices of science. “Science affects and is affected by the various elements and contexts of the culture in which it is practiced” (Lederman & Lederman, 2004, p. 6). Global approaches to solving science related problems are influenced by cultural and social contexts such as politics, social values, socioeconomic factors and religion. It is important for students to learn how to make informed responsible decisions about situations in which science has a role, such as socio-scientific, environmental and technological issues.

b. Attitudes towards science

Attitudes towards science affect students' interest in and support for science and technology. A relationship exists between students' interest in science, achievement in science and future career choices. Engaging and stimulating learning experiences in science-related activities frame science as a valuable and interesting pursuit in its own right. It is important for students to experience the joy of scientific discovery and develop their natural curiosity about the world around them.

4. Metacognitive thinking

Metacognitive thinking involves knowledge of cognition in general as well as awareness and knowledge of one's own cognition; for example, knowledge of comprehension self-monitoring strategies, self-knowledge and awareness about one's own motivation (Fisher & Frey, 2008; Lai, 2011). Since it is important in all aspects of science learning, it is written in the Table in the left-hand side of Table 2.3 spanning all three categories. Metacognitive thinking skills can increase students' motivation for their own learning (Lai, 2011). Teaching metacognitive thinking skills can help students to become more informed, purposeful and autonomous learners who know how to reflect upon their own learning (Lai, 2011; Fisher & Frey 2008; Hennessey, 1999). Metacognitive thinking skills important for learning include *self-reflective strategies* for regulating one's own learning; *critical thinking strategies* for problem solving, developing and critically analysing claims, and using evidence for making reasoned conclusions; *creative thinking strategies* for generating and applying new ideas, identifying alternative explanations, and making new connections between learning and outcomes (Lai, 2011; Yore, Pimm & Tuan, 2007; Osborne, 2007).

2.1.7. Using the framework from the literature to categorise scientific literacy in the Australian Curriculum

The objectives of scientific literacy are generally reflected in curriculum documents as statements of learning and standards to achieve. In the following analysis of the Australian Curriculum, the four categories distilled from the literature (factual and conceptual knowledge of science, scientific inquiry, attitudes about and towards science and metacognitive thinking) have been used as a framework for categorising the key elements of scientific literacy. This is illustrated in Table 2.4. The four categories of scientific literacy distilled from the literature are embedded in the Australian Curriculum (2015) within three interrelated strands: *Science Understanding, Science as a Human Endeavour* and *Science Inquiry Skills*. The rationale for how these three strands together shape the development of scientific literacy from Prep to Year 12 is outlined in the Australian Curriculum (ACARA, 2015):

> The Australian Curriculum: Science provides opportunities for students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, of science's contribution to our culture and society, and its applications in our lives…. The wider benefits of this "scientific literacy" are well established, including giving students the capability to investigate the natural world and changes made to it through human activity. (Rationale, para. 1, 2)

Table 2.4

Aspects of the four categories of scientific literacy in the Australian Curriculum

Category	Key aspect
Factual and conceptual knowledge of science	Science Understanding (SU) Biological sciences; Chemical sciences; Earth and Space sciences; Physical sciences
Scientific Inquiry	*Science Inquiry Skills (SIS)* Identifying and posing questions; Planning, conducting and reflecting on investigations; Processing, analysing and interpreting evidence; and Communicating findings General Capability: Literacy 1. Comprehending texts through listening, reading and viewing 2. Composing texts through speaking, writing and creating. General Capability: ICT 1. Applying social and ethical protocols and practices when using ICT 2. Investigating with ICT 3. Creating with ICT 4. Communicating with ICT 5. Managing and operating ICT *General Capability: Intercultural understanding* 1. Recognising culture and developing respect 2. Interacting and empathising with others 3. Reflecting on intercultural experiences and taking responsibility
Attitudes towards and about Science	Science as a Human Endeavour (SHE) 1. Nature and development of science 2. Use and influence of science
Metacognitive thinking	General Capability: Critical and creative thinking 1. Inquiring – identifying, exploring and organising information and ideas 2. Generating ideas, possibilities and actions 3. Reflecting on thinking and processes 4. Analysing, synthesising and evaluating reasoning and procedures

Source (ACARA, 2015)

2.1.8. Summary

While the science education community has not reached consensus on a common meaning of scientific literacy, it is generally agreed that an essential characteristic of scientific literacy is the ability to use the science knowledge and skills one possesses in real-life, every day contexts in a critical way (Aikenhead et al., 2011; Champagne, 1992; Eisenhart, Finkel & Marion, 1996; Goodrum & Hackling, 2001; National Research *National science education standards*, 1996; OECD, 2007; Roberts, 2007). Scientifically literate people possess "the ability to act (not merely to know) and the promise of widespread use. Literate persons not only possess knowledge, but they use knowledge in varied contexts and for worthwhile purposes and in a socially responsible way" (Eisenhart et al., 1996, p. 282).

Aspects of the four categories of scientific literacy are represented in the Australian Curriculum, but the extent to which they are transferred into learning outcomes for students at different levels is unclear. Scientific Inquiry clearly emerges from the literature as an important aspect of scientific literacy. While it includes the scientific processes of science such as hypothesising and experimenting as described in Robert's Vision I, it requires the user to combine these skills with scientific reasoning and critical thinking to develop scientific knowledge and an understanding of the nature of science in real world contexts according to Robert's Vision II. How can a primary science teacher design instructional learning experiences that help students develop positive attitudes towards science, understand the processes of science inquiry, learn factual and conceptual knowledge and reflect on their own learning (metacognitive thinking)? The centrepiece of my research agenda is understanding and developing viable ways to support teachers and students in using and understanding Scientific Inquiry as an approach to developing scientific literacy.

2.2 Conceptualisation of Scientific Inquiry

Scientific Inquiry (SI) reflects how scientists come to understand the natural world and propose explanations based on the evidence derived from their research. Notwithstanding debate about the nature of scientists' work and the limitations of the concept of scientific method (Latour & Woolgar, 1979), there is some consensus around the meaning of scientific inquiry in education as evidenced by the following assertion by Yore (2012):

> Scientific Inquiry is a creative, dynamic, and recursive process. There is no universal, lockstep scientific method. Authentic science involves a cycle of false starts, unproductive moves, repeated trials, and revised procedures leading to knowledge claims and explanations. (p. 128)

Scientific Inquiry is often referred to as the process of science, however, as Lederman and Lederman (2011) proclaim:

> Scientific Inquiry extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting, and analysing data. It involves the combination of process skills with scientific knowledge, scientific reasoning, and critical thinking to develop scientific knowledge. (p. 128)

In addition, Scientific Inquiry refers to knowing *about* the inquiry process. Venville and Dawson (2004) argue scientific inquiry processes depend on the nature of the questions being explored, which in turn depend on the specific scientific disciplines. Hence, a depth of understanding of the broader process is necessary to be able to develop investigations in different fields.

In the Australian context, the Australian Curriculum has attempted to capture this depth by conceptualising science inquiry. Science inquiry is defined in the Content Structure of the Australian Curriculum (ACARA, 2015):

> Science inquiry involves identifying and posing questions; planning, conducting and reflecting on investigations; processing, analysing and interpreting evidence; and communicating findings. This strand is concerned with evaluating claims, investigating ideas, solving problems, drawing valid conclusions and developing evidence-based arguments. (para. 13)

SI, as an educational objective, has been viewed as a set of abilities and process skills that students develop, and as a set of cognitive understandings. Unfortunately, there has been little research on students' views and teachers' understandings about inquiry.

Lederman and Lederman (2011) argue that the development of scientific literacy requires an individual to understand subject matter, nature of science (NOS), and scientific inquiry (SI). The challenge faced by teachers is how to integrate the three areas. Traditionally, more emphasis is placed on teaching subject matter, "When a teacher attempts to integrate NOS and SI into instruction there is a real, or perceived, tension created that less time is devoted to the learning of subject matter" (Lederman & Lederman, 2011, p. 127).

2.2.1. Research on Scientific Inquiry

Teachers' conceptions of SI are diverse and students' understandings are also limited. Many reasons may be sought to explain why teachers struggle with conceptualising the meaning of SI and the NOS. However, researchers engaged in the study of inquiry have reported that conflicting definitions of inquiry with little guidance for the actual planning, teaching and evaluation of SI in the science classroom have contributed to diverse understandings of the term (Keys & Kennedy, 1999). The various interpretations of SI, as noted by Lederman and Lederman (2011, p. 129), have contributed to teachers' misunderstandings; "SI has always been ambiguous in its presentation within science education reforms". There is confusion between learning a discipline and practicing a discipline. Scientific Inquiry as a teaching approach used to facilitate students to construct their own scientific knowledge as opposed to an educational learning outcome encompassing the processes that scientists use when doing inquiry (e.g., posing questions, observing, inferring, analysing data, etc.) has lead to varying approaches to the implementation of inquiry (Kirschner, Sweller & Clark, 2006; Lederman & Lederman, 2011).

Furthermore, some evidence of the conflicting views primary teachers have around teaching inquiry has been highlighted in a phenomenographic study by Ireland et al. (2012). The three different conceptions of inquiry that emerged in the study were:

> (a) The Experience-centred conception where teachers focused on providing interesting sensory experiences to students; (b) The Problem-centred conception where teachers focused on challenging students with engaging problems; and (c)

> The Question-centred conception where teachers focused on helping students to ask and answer their own questions. (p. 159)

Students' understandings are also limited. Carey, Evans, Honda, Jay, and Unger (1989) researched Year 7 students' views of inquiry and nature of science within authentic inquiry situations. Seventy-six students in five, mixed ability Year 7 science classes in a K-8 public school in Boston participated in the study. A clinical interview was used to assess students' epistemological views prior to and after exposure to a teaching unit especially developed to introduce the constructivist view of science. Results of the study revealed that most students have naïve understandings about SI and the NOS. Carey et al. (1989) also explored students' views of scientific knowledge and their understanding of how scientists conducted scientific investigations. After being engaged in an authentic inquiry about bread dough rising, Year 7 students' inability to draw evidenced based conclusions from their experiment lead Carey et al. (1989) to conclude that the students lacked process skills and had limited understanding about the nature and purpose of experiments.

Continuing the research agenda on SI and NOS, Lederman and Lederman (2011) found students' views of the nature of scientific knowledge and their understandings about inquiry were not necessarily parallel to each other. They analysed the work by Carey et al., (1989) suggesting the epistemology of science defined by these authors includes not only the nature of scientific knowledge (e.g., scientific knowledge is changing) but also understandings about inquiry (e.g., evidence-based explanation). Hence, Lederman and Lederman (2011) recommend that the *understandings about inquiry* should be considered separately from epistemology of science and nature of science.

In response to the need to develop a more detailed understanding of the interrelationships between the various instructional approaches for teaching Scientific Inquiry and their impact on student learning outcomes in different contexts, a more explicit instructional model of how to teach Scientific Inquiry is needed. Venville and Dawson (2004) highlight the need to explicitly encourage reflection about the NOS and SI by discussing with students the implications they have for the way students view scientists, scientific knowledge and the practice of science. It is believed that students' ability to make informed scientific decisions about personal and societal problems is a critical component of scientific literacy and is influenced by their conceptions of the NOS and Scientific Inquiry. If students are expected to develop more adequate conceptions of the NOS and Scientific Inquiry, research that identifies effective instructional methods is crucial. The next section explores the design of effective instructional approaches for teaching Scientific Inquiry and how this translates to classroom practice and subsequent learning outcomes for students.

2.2.2. Instructional approaches

A goal of effective instruction is to provide a positive nurturing environment that facilitates students to independently apply what they have learned to new or novel situations. It has been argued that in-depth conceptual understanding of science subject matter is dependent on students' understanding of NOS and Scientific Inquiry. This idea is supported by Anderson and Bloom (2001) who stated: "In combination, conceptual knowledge and deep understanding can help individuals as they attempt to transfer what they have learned to new situations" (p. 42). The teaching of the NOS and SI have been the subject of recommendations in science education reforms and literature currently and in the past. However, Venville and Dawson (2004) claim that the recommendations have had little impact on students' understanding of the NOS and SI.

There are many instructional models, which include direct or explicit instruction, cooperative learning, and inquiry-based learning. Instructional models are methods of teaching or underlying philosophies that guide teaching methods (Fisher & Frey, 2008; Anderson & Bloom, 2001). In considering the effectiveness of various instructional models for teaching Scientific Inquiry Skills, it is important to identify the underlying philosophies that guide each teaching method. The various models of instruction can be placed broadly on a continuum from direct at one end of the spectrum to minimally guided approaches at the opposite end. In the next section, I discuss four instructional designs that are used in teaching primary students as well as the underlying philosophies that guide each teaching method: minimally guided instruction, direct instruction, GRR, and collaborative learning.

2.2.3. Minimally guided instruction

In instructional settings, learners are assumed to construct their own meaning based on their prior knowledge, their current cognitive and metacognitive activity, and the opportunities and constraints they are afforded in the setting, including the information that is available to them (Anderson & Bloom, 2001). Minimally guided instruction is one approach that uses constructivism as a referent for practice. The view that "knowledge is organised and structured by the learner in line with a rationalist-constructivist tradition" (Anderson & Bloom, 2001, p. 41) is the foundation of assumption underlying the constructivist learning model of instruction. The view that knowledge is constructed by humans is central to the Vygotskian social constructivist perspective (1978). According to this conception of learning, an active, cognitive, and constructive process facilitates meaningful learning through the interaction among learner and knowledgeable others.

A minimally guided approach to teaching science was adopted by many curricula of the late 1960's and 1970's (Bruner, 1961). The *implicit* instructional model suggests that by doing hands-on inquiry-based activities students will develop an understanding of the NOS and SI (Lawson, 1982). Kirschner et al. (2006) describe two main assumptions underlying instructional programs using minimal guidance. The first assumption is that students learn best when challenged to solve "authentic" problems within information-rich learning environments. Authenticity in the science classroom demonstrates or replicates the kinds of work scientists do and is relevant to students (Braund & Reiss, 2006; Gaskell, 1992; Roth, 1995). However, "just moving the practices of scientists into the classroom without some modification of the science content and methods to match the developmental level of students is not appropriate" (Crawford, 2012, p. 27). A second assumption of programs using minimal guidance is that by simply replicating the experiences of real scientists in a classroom, students will acquire scientific knowledge implicitly with minimal process or task-relevant information being offered on a needs basis (Kirschner et al., 2006). Furthermore, advocates of this approach have implied that instructional methods that embed explicit learning strategies interfere with the natural processes by which learners draw on their unique prior life experiences and learning styles to construct new understandings.

Both approaches are underpinned by a constructivist view of learning which has become increasingly more popular in recent years, however, its interpretation has varied in educational settings. Research has shown that many students do not make the important connections between and among the facts they learn in classrooms and the larger system of ideas reflected in an expert's knowledge of a discipline (Anderson & Bloom, 2001) without support of the teacher scaffolding the interactions at both whole group and individual levels (Watters & Diezmann, 1998).

The effect of minimally guided instruction on discovery learning has been criticised by (Yore, 2012); "Engaging students in hands-on experiences with no guided reading and writing about what has been experienced has minimal effect on learning" (p. 14). In a review of evidence from studies conducted from 1950 to the late 1980s comparing unguided discovery learning and problem-based instruction with guided forms of instruction, Mayer (2004) suggests that the unguided approaches have not been supported. Mayer criticises pure hands-on discovery activities for being so open that students may not come into contact with the material to be learned and failing to provide appropriate cognitive processing. Mayer suggests that instruction that provides a mixture of guidance and exploration is needed. "The challenge of teaching by guided discovery is to know how much and what kind of guidance to provide and to know how to specify the desired outcome of learning" (Mayer, 2004, p. 17). Dean Jr. and Kuhn (2006) conclude that a gradual and extended process of acquisition and consolidation was more successful in scaffolding students' mastery of the control-of-variables strategy central to the scientific method.

Pursuing this further, Ireland et al. (2012) recommend that teachers and pre-service teachers look toward practices that scaffold student inquiry learning answering their own questions. Such scaffolded inquiry through minimally guided instruction may afford students opportunities to learn Science Inquiry

Skills.

2.2.4. Direct Instruction

Venville and Dawson (2004) emphasise that students' understanding of the NOS and Scientific Inquiry is not an implicit by-product of doing science-based or inquiry-based learning activities: "If students are expected to develop more adequate conceptions of the NOS and scientific inquiry this outcome should be planned, explicitly taught and assessed" (Venville & Dawson, 2004, p. 15). Advocates of direct instruction propose that high levels of skill and knowledge are more likely developed when instruction involves considerable modelling, guidance, feedback, peer and teacher support and much practice. As time progresses learners become proficient and develop expertise (Adams & Engelmann, 1996; Archer & Hughes, 2011; Fisher & Frey, 2008; Kirschner et al., 2006; Rosenshine, 1995). Direct instruction, as a theory of education, posits that the most effective way to teach is by explicit, guided instruction. This method of teaching directly contrasts other styles of teaching, which are more minimally guided and encourage exploration. Direct instruction is a very common teaching strategy but can be interpreted in various ways. Some may view direct instruction as the use of strict lesson plans and lectures with little or no room for variation. It may also be considered to be inflexible and overly reliant on "teacher talk" with little or no hands-on activities or discussion. In this thesis direct instruction refers to the teacher giving instruction, however, during this time students are not just passively receiving knowledge but rather cognitively engaged through thinking.

A body of early research summarised by Rosenshin and Stevens (1986) identified instructional procedures that influence student learning outcomes. Two findings from that research identified instructional procedures that are most relevant to teaching. These include (1) the importance of teaching in small steps and (2) the importance of guiding student practice. Rosenshin and Stevens (1986) grouped the instructional procedures of an effective teacher drawn from research under six "functions" as outlined in Table 2.5.

Table 2.5

Six teaching functions of an effective teacher

Function	Strategy
Review	Review homework and relevant previous learning Review prerequisite skills and knowledge
Presentation	State lesson goals Present new material in small steps Model procedures Provide examples and non-examples Use clear language Avoid digressions
Guided practice	Require high frequency of responses Ensure high rates of success Provide timely feedback clues, and prompts Have students continue practice until they are fluent
Corrections and feedback	Reteach when necessary
Independent practice	Monitor initial practice attempts Have students continue practice until skills are automatic
Weekly and monthly reviews	Review word lists, word sounds, number facts, and mathematical procedures Checking homework Students give the teacher feedback on homework Students check each other's papers Reteach or provide additional practice where necessary

More recently, Hattie (2009) investigated effective teaching strategies by developing a way of ranking various influences, which are related to learning outcomes according to their effect sizes. In a meta-analysis of 50,000 research articles the overall average effect from all meta-analysis of the interventions he studied was d = 0.40. Hattie identified this as important because it is close to the average effect that we can expect from a year's schooling. Therefore, he decided to judge the success of the many variables that influence learning relative to this finding. It is interesting to note that Hattie concurred with some of Rosenshin and Stevens' attributes of an effective teacher. For example, he presents evidence that feedback is among the most powerful influences of successful teaching with an average effect size of 0.79, and setting learning goals has an above average effect size of 0.50. Both (feedback and establishing learning goals), are important steps in direct instruction outlined by Adams and Engelmann (1996).

The effectiveness of direct instruction is supported by substantial research (Adams & Engelmann, 1996; Archer & Hughes, 2011; Hattie, 2009, 2012; Hollingsworth & Ybarra, 2009; Kirschner, et al., 2006; Marzano, 2007; Rosenshin & Stevens, 1986; Rosenshine,1995) and it is one of the few scientifically verifiable ways to improve student learning outcomes. Hattie (2009, p. 65) found that "direct instruction's average effect size of d = 0.59 places it in among the more successful programs of which we are aware". The general message from the overall d = 0.59 is that the effects of direct instruction are above the average of 0.04.

This evidence has resulted in widespread support of direct instruction in education systems throughout the world. While teaching solely through direct instruction has been shown to disengage students in science (Tytler, 2007) a combination of approaches may be more suitable for teaching SIS in the classroom.

2.2.5. Gradual release of responsibility model of instruction

Effective teachers will integrate different models of instruction depending on the students that they are teaching and the needs and learning styles of those students. It is possible to merge aspects of more than one instructional model to provide authentic opportunities for formulating inquiry and engaging problem solving while emphasising a controlled shift of the balance of joint responsibility between teacher and students.

An instructional model developed by Pearson and Gallagher (1983) proposes that the cognitive load should shift slowly and purposefully from teacher-as-model, to joint responsibility, to independent practice and application by the learner. In this model, the teacher transfers the responsibility of performing a task gradually to students over a period of time, which may be an hour, a week, months or longer depending on the complexity of the skill being taught. The Gradual Release of Responsibility (GRR) theory of learning differs from traditional views of explicit instruction by suggesting that "learning occurs through interactions with others, and when these interactions are intentional, specific learning occurs" (Fisher & Frey, 2008, p. 3). Students scaffold each other's learning when emphasis is placed on the role of peer-peer interaction, language and discourse in the development of understanding (Vygotsky, 1978). In a review of research on peer learning in primary schools, Thurston et al. (2007) reported "science lends itself readily to incorporating peer learning initiatives as it often involves practical investigatory work" (p. 490).

An effective model for the GRR (Pearson & Gallagher, 1983) proposed by Fisher and Frey (2008) moves from modelled to guided instruction, followed by collaborative learning and finally independent experiences. A framework for implementing the GRR model is *I do it, We do it, You do it, You do it together* (Fisher & Frey, 2008). In the GRR model it is important to emphasise that interactions should not be limited to adult and child exchanges, but provide opportunities for learning through collaboration with peers. There are four distinct instructional stages contained within the GRR model. These include focus lessons (I do it), guided instruction (We do it), collaborative learning (You do it together), and independent tasks (You do it alone). This model sequences instruction as follows:

1. Focus lesson phase (I do it) which involves the teacher setting the purpose for learning and providing direct explanations with modeling and think-alouds.
2. Guided instruction phase (We do it) where the teacher scaffolds students' hands-on application of the new learning and provides feedback, cues and prompts.
3. Collaborative learning phase (You do it together) requires the teacher to provide opportunities for students to collaborate with peers using what they have been taught during the focused and guided instruction phases.
4. Independent phase (You do it alone) where students independently apply new learning in unique situations.

The framework for implementing the GRR is illustrated in Figure 2.1.

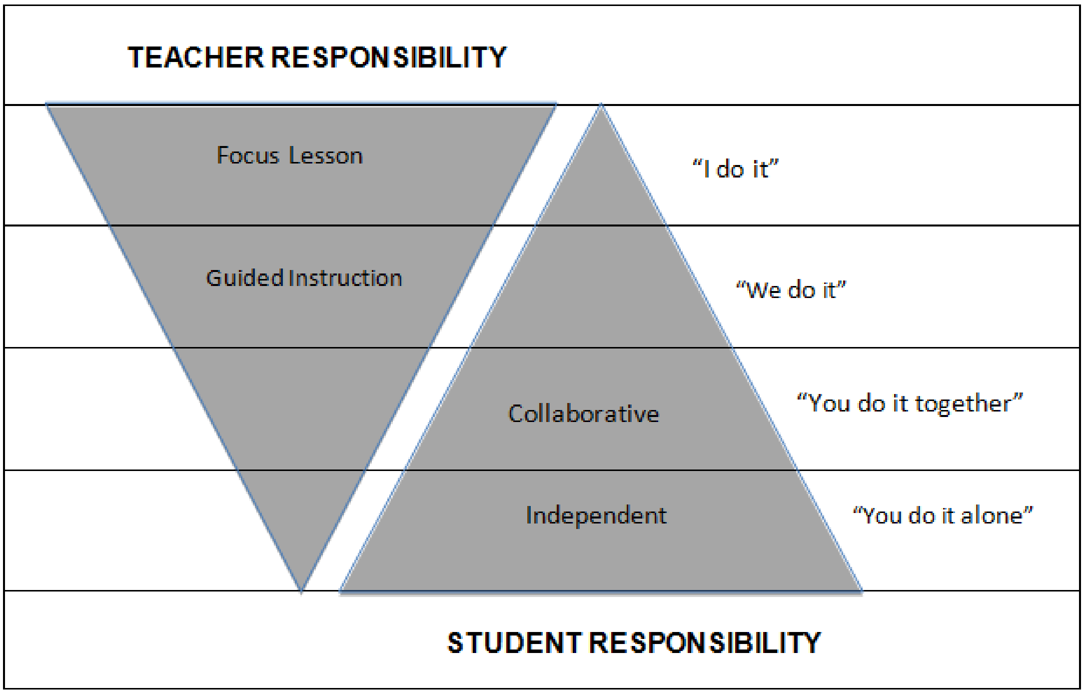


Figure 2.1 A structure for successful instruction (Fisher & Frey, 2008)

Fisher and Frey (2008) describe the GRR model as emerging from a combination of several theories, including the theory of cognitive structures and schema (Piaget, 1952), the concept of the zones of proximal development (Vygotsky, 1962; Vygotsky, 1978), attention, retention, reproduction and motivation (Bandura, 1965), as well as the theory of scaffolded instruction (Wood, et al., 1976). Piagetian ideas of accommodation and assimilation, together with Vygotsky's (1962, 1978) view that learning involves a passage from social contexts to individual understanding, together with Bandura's (1965) work on attention, retention, reproduction, and motivation, and Wood, Bruner and Ross's (1976) work on scaffolded instruction underpin the GRR model of instruction. These three theories together recommend that learning occurs through interaction with others, and through these intentional interactions, specific learning occurs (Fisher & Frey, 2008).

2.2.6. Collaborative learning

Collaborative learning has an important role to play in primary school science. Vygotsky's (1978) social constructivist perspective that scientific knowledge is socially constructed in the classroom, influenced by existing ideas, internally validated and communicated is widely supported. However, the teacher's role in this process is critical. Collaborative learning provides a framework for students to refine their thinking about new concepts and skills. The group context requires the use of social and academic interaction and provides a forum for the development of scientific oral language development. Designing effective collaborative learning activities can be a challenge because so much of the activity occurs outside the presence of the teacher. The role of the teacher is challenging, requiring consideration of many factors such as establishing the purpose of the activity, configuration of the groups, group accountability strategies, protocols, to mention just a few. The complexity of designing collaborative learning experiences that scaffold students to socially construct science knowledge was explored by Driver, Asoko, Leach, Mortimer, and Scott (1994):

> Although learning science involves social interaction, in the sense that cultural tools of science have to be introduced to learners, individuals have to make sense of newly introduced ways of viewing the world. If everyday representations of particular natural phenomena are very different from science representation, learning may prove difficult. There is a need for instructional methods that manage and modulate the information processing demands upon the learner so they are not too much or too little. (p. 11)

Consequently, Driver et al. (1994) concluded that the two important roles of the teacher are to (1) introduce new ideas or cultural tools where necessary, and (2) provide the support and guidance for students to make sense of these themselves.

There has been a wide range of research into the ways of organising classrooms so as to reflect particular forms of collaborative inquiry that can support students in gradually mastering the norms and practices that are deemed to be characteristic of scientific communities (Driver, et al., 1994; Gillies, et al., 2011; Hackling, et al., 2007). However, there has been little research on using the GRR model of instruction for teaching SI. The GRR draws on several learning theories, which, taken together suggest learning occurs through guided interactions with others.

2.2.7. Summary

Results of studies have reported the success of GRR in language learning and literacy development (Fisher & Frey, 2003; Griffith, 2010; Lin & Cheng, 2010b); however, the GRR model can also be employed in other educational contexts and serve as a framework for helping students learn about Scientific Inquiry, particularly given its emphasis on collaborative learning. Consequently, this thesis argues that the GRR framework may allow teachers to play an active role in scaffolding all students to develop any number of skills, including Scientific Inquiry Skills.

2.3 Conclusion

Scientific Inquiry is an important aspect of scientific literacy, and is represented as a strand of learning in the Australian Curriculum (the intended curriculum). Scientific Inquiry extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting, and analysing data. It involves the combination of process skills with scientific reasoning, and critical thinking to develop scientific knowledge. Ultimately, whether or not a large proportion of students develop an understanding of Scientific Inquiry is almost entirely dependent on teachers and the effectiveness of their pedagogical practices (the enacted curriculum).

Addressing the need to provide assistance for science teachers to improve their pedagogy, Rosenshin and Stevens (1986) identified instructional procedures that influence student learning outcomes that are most relevant to teaching. These include (1) the importance of teaching in small steps and (2) the importance of guiding student practice. Continuing on this idea, Driver et al. (1994) propose that the two important roles of the teacher are to (1) introduce new ideas or cultural tools where necessary, and (2) provide the support and guidance for students to make sense of these themselves. Conceptualising what all this means for primary science teachers in classrooms raises questions about how this research can be transformed into practice.

Ireland et al. (2012) have provided insight into teachers' various conceptions of teaching science inquiry and make recommendations for primary teachers to implement high quality instruction that has positive long-term effects on students' learning and understanding of science inquiry which can lead to improved scientific literacy. Hence, there is a need to extend our understanding of appropriate instructional procedures that are proven to be effective in real primary classrooms for teaching Science Inquiry Skills to students.

This thesis proposes that through a scaffolded approach using the GRR model of instruction, teachers can guide their students towards developing an understanding about Scientific Inquiry leading to the foundations of scientific literacy. Therefore, the purpose of this study is to examine how a year-4 teacher implemented the GRR model for teaching SIS to primary school students. In such a way, students were afforded the opportunity to learn about Scientific Inquiry.

Chapter 3 **Methodology**

3.1 Introduction

The previous chapter discussed the theoretical background to the study. The purpose of this chapter is to justify and provide details of the methodological approach that will be used to accomplish the aim of this study: specifically,

> *To explore how a primary teacher implemented the Gradual Release of Responsibility model of instruction to teach Science Inquiry Skills in a year-4 classroom.*

The following section begins with a discussion of the methodology in relation to research paradigms (Section 3.2), and situates the current case study research within the paradigm of qualitative research. It explains how the theoretical paradigm is connected with the inquiry approach and research design (Section 3.2.1). An overview of case study research follows (3.2.2) with particular focus on defining the case study types (Section 3.2.3). The research questions are elaborated in relation to data collection (Section 3.2.4). Each component of the research methods is clarified (Section 3.3): the setting and the participants; the trial of coaching in Science, the main study data collection instruments and analyses. The data sources and analysis of the case study research are explained, including details of the analysis of teacher data sources (3.3.5) followed by analysis of student data sources (3.3.6). The chapter concludes with a discussion of ethical and potential problems (3.4) and limitations of the proposed research (3.5).

3.2 Research paradigms

According to Guba and Lincoln (1994) a paradigm may be viewed as a set of basic beliefs: “It represents a worldview that defines, for its holder, the nature of the ’world’, the individual’s place in it, and the range of possible relationships to that world and its parts” (p. 107). Research paradigms described by Guba and Lincoln (1994) are explained according to their ontology, epistemology and methodology. They describe four major paradigms including positivist, postpositivist, critical theory and the constructivist paradigm. The epistemology of positivists assumes that an apprehendable reality exists. Positivists are closest to being scientific and are associated with quantitative methods. Postpositivists assume that an imperfect reality exists and is probably apprehendable. A critical theory approach adopts ontology of historical realism in which a virtual reality is shaped by social, political, cultural, economic, ethnic, and gender values and becomes evident over time. The constructivist paradigm emphasises the need to understand the human experience whereby the role of the inquirer is cast in the role of participant and facilitator in this process. The epistemology of a constructivist view "assumes multiple, apprehendable, and sometimes conflicting social realities that are the products of human intellects, but that may change as their constructors become more informed and sophisticated" (Guba & Lincoln, 1994, p. 111). A constructivist paradigm is closely aligned with qualitative research that involves a focus involving an interpretive and naturalistic approach to its subject matter.

3.2.1. Ontological and epistemological perspectives

This study is positioned within qualitative assumptions of research and reflects a constructivist paradigm. The nature of this qualitative research is to explore a phenomenon (year-4 teachers' science pedagogy) for patterns of unanticipated as well as expected relationships. Qualitative research places emphasis on providing a rich insight into human behaviour through looking closely at people's words, actions and records (Guba & Lincoln, 1994). The connection between teacher and learner is central to this study and guides the epistemology (i.e., the nature of the relationship between the knower or would-be knower and what can be known). This study is set in a real-world context (classroom) whereby the investigator and the object of investigation (the year-4 teacher) and her class are interactively linked so that the "findings" are literally created as the investigation proceeds. A relativist ontological perspective is adopted and described by Guba and Lincoln (1994):

> Realities are assumed to exist as apprehendable in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature, and dependent for their form and content on the individual

> person or groups holding the constructions" (p. 111).

The study aims to gain an in-depth understanding of a year-4 teacher's developing science pedagogy and the outcomes for students, within a clearly defined context of one classroom, and with an identified beginning and end time for the study. Thus, case study research offers a complementary research design to connect the theoretical paradigm with the inquiry approach.

The following sections discuss case study types and the perspectives of this study. The case study of this thesis is explained and the research methods are detailed.

3.2.2. Overview of case study research

The case study is but one of several ways of doing social science research. Other ways include but are not limited to quasi-experiments, survey, narratives, ethnography, phenomenology and grounded theory. This study aligns with multiple elements of case study design described by Yin (2009) as elaborated below.

Case study research is a methodology appropriate for deriving an intimate and in-depth understanding of a single or small number of cases within an authentic real life context. Yin (2009) describes case study research as:

> An empirical inquiry about a contemporary phenomenon (e.g., a "case"), set within its real world context – especially when the boundaries between phenomenon and context are not clearly evident. (p. 18)

Like other research methods, case study research provides a rigorous methodological path that includes procedures central to all types of research methods, such as protecting against threats to validity and maintaining a chain of evidence. It provides an approach for understanding the ways in which a year-4 teacher implements the GRR in her year-4 Science class with multiple sources of evidence. A positive feature of case study research is that it can include both qualitative and quantitative data sources. While the majority of the data collected in this research will be qualitative, the ACER (Australian Council for Educational Research) nationally normed Progressive Achievement Test in Science (PATScience) will provide quantitative information about students' levels of achievement of the concepts, skills and processes of science (Martin, Urbach, Hudson, & Zoumboulis, 2009). Furthermore, case study research can include other features that are not critical for defining the method, but may be considered variations within case study research for providing answers to common questions (Yin, 2009). For example, case study research includes both single and multiple case studies. While the teacher is the focus of the study, individual students within a group are used for individual analysis. Also, case study research may be used when the investigator has little control over the outcomes. This point is particularly relevant in this case study of an individual teacher's developing science pedagogy. As such, the autonomy of the teacher's practice means that there is no clear single set of outcomes.

In the following Section (3.2.3) an outline of the general characteristics of case study research designs serves as a background for justifying the most suitable design for this research.

3.2.3. Case study design

The types of case study are identified by Yin (2012) according to the kind of research question that a study is trying to address. These are elaborated in Table 3.1.

Table 3.1

Types of case studies (Yin, 2012)

Type of case study	Purpose
Descriptive case study	Research what is happening or has happened?
Explanatory case study	Research how or why did something happen including a consideration of "how" and "why" (rival explanations)
Case study evaluation	Evaluating some kind of initiative

This study seeks to answer how and why questions and hence Yin's approach to case study is appropriate for this study. Explanatory case study design matches the purpose of this research, that is: seeking to explain how and why outcomes occur. This type of case study has the potential to uncover explanations about the teacher-student relationships to enrich the understanding of a phenomenon (the teacher's pedagogy). Searching for and testing rival explanations can strengthen the credibility of an explanatory case study. Yin (2012), describes the benefits of this technique, "When case studies include the investigation of such rivals, and if the prevailing evidence can support their rejection, you can place greater confidence in your case study's original explanation and conclusions" (p. 90). The explanatory case study is appropriate for the purpose of this study to answer the overarching question, "How does the teacher implement the GRR model of instruction to teach Scientific Inquiry Skills (SIS) in the classroom?"

Yin also describes four types of case study design. They are "(Type 1) single-case (holistic) design, (Type 2) single-case (embedded) designs, (Type 3) multiple-case (holistic) designs, and (Type 4) multiple-case (embedded) designs" (Yin, 2009, p. 47). These designs all facilitate analysis of contextual conditions in relation to the "case" with an expectation that "the boundaries between the case and the context are not likely to be sharp" (Yin, 2009, p. 46).

When aligning the current study with one of Yin's four designs, the major factor in selecting the most suitable design is whether or not subunits are identified within the single-case study. The single-case may involve more than one unit of analysis, for example, the main unit is the "teacher's pedagogy" as a whole, and the smallest unit is the individual class member or "individual student". While the holistic case is about how a teacher implements science pedagogy, the study could include data collected from individual students – whether from a survey, from an analysis of the student's artefacts (assessments, science journal, conversations). Therefore the possible choices are either (Type 1) single-case (holistic) design or (Type 2) single-case (embedded) design.

The nature of qualitative research is to explore a phenomenon, in this case teacher's pedagogy; therefore this research will use an explanatory case study design of Type 2. This is a single case (classroom) with embedded designs or groups of students that are examined as part of the case.

3.2.4. Research questions

Attention to matching the questions with appropriate procedures of inquiry is an important component in choosing the methodology, as is consideration of the real-life context. Yin's (2009) case study design is appropriate, when "how" or "why" questions are posed. The aim of this study is to answer the overarching question, "How does the teacher implement the GRR model of instruction to teach Scientific Inquiry Skills (SIS) in the classroom?" To address this aim I pose three research questions which are elaborated in Table 3.2.

Table 3.2

Elaboration of the Research Question, Evidence and Data Collection

Sub-questions	Theoretical Framework	Data Generation Instruments
1. What strategies does the teacher use to implement Science Inquiry through GRR practices in a year-4 Science class?	GRR model (Pearson & Gallagher, 1983) Framework for the GRR (Fisher & Frey, 2008) I do it We do it You do it together You do it alone	Teacher's artefacts Video/Audio recordings of classroom talk Teacher & researcher reflective journals Photographic evidence
2. What affordances/ constraints does the teacher identify in using these strategies?	Framework for the GRR	Informal teacher interviews Teacher reflections
3. What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR	Instructional Coaching Theory GRR Framework for the GRR	PATScience assessment Student artefacts Formative assessments Observations

model?		Student and teacher reflections Student post-teaching survey

As outlined in Chapter 2, there is a need to explore how the GRR model of instruction can guide the teaching of Scientific Inquiry Skills (SIS) in the classroom. A set of supporting questions helps to make more explicit the teaching of SIS referred to in the overarching question. Table 3.5 in Section 3.3.4 expands the overarching research question into sub-questions and links its elements to the required evidence and the tools for collecting that evidence. The nature and purpose of each of these data collection methods are discussed later in Section 3.3.2.

3.3 Research Methods

This section describes the context of the study, selection of the case participants, details of the data sources, data analysis procedures and ethical issues. Initially, it is important to state that the researcher is a teacher at the school in which the study was based.

3.3.1. Setting

The study was based in one classroom in a government primary school of about nine hundred students aged between 5 – 12 years and twelve years from Prep to Year Seven, located in a relatively affluent inner suburb of an Australian capital city. The classroom setting provided a context to examine the phenomenon within its real-world context. The setting for this study was relatively natural for both teacher, researcher and the students because (a) it was conducted within their own school environment; (b) it was based on the Australian Science Curriculum that is the prevailing national curriculum.

3.3.2. Participants

The Teacher

The teacher participant was qualified with a Bachelor of Education and a Bachelor of Nursing. Her pseudonym was Stella. Stella's experience in science included participation in a number of professional development workshops conducted by the Science Teachers' Association of Queensland (STAQ) and the Queensland Education Department's *Science Spark* initiative. She was an experienced primary school teacher of seven years known to the researcher, hence a convenience sample. A convenience sample in this instance is one in which the researcher uses a colleague that is available to participate in the research study. Stella demonstrated particular enthusiasm in regard to participating in the Science coaching trial as well as this research study. During her four years teaching at the school she had participated in the trial of coaching in Science (outlined in Section 3.3.3) and supported school and community Science events, including the Science Teachers' Association of Queensland (STAQ) annual science conference, *Science is Primary*. The teacher's experience also included teaching science lessons in all Prep to Year 7 classes in the school. The GRR underpins the school's pedagogical framework, and as such, the teacher had routinely used the pedagogy and language of the GRR, "I do it", "We do it", "You do it together" and "You do it alone" when teaching subjects other than science in her year-4 classroom. The teacher was selected because of her prior experience using the GRR model.

Students

The teacher's class consisted of 28 students aged between 9 and 10 years. The main language spoken at home was English, however other languages spoken at home included Chinese and Greek. All but three students agreed to participate and those who didn't were located out of view of video camera. In accordance with the ethical agreement, any students who did not participate were not video-recorded. Additionally, consent was sought from students and the teacher participant to use images in professional development presentations for teachers in schools as well as conference presentations.

Further details of the participants' profiles are discussed in Chapter 5 in the context of the study's findings.

3.3.3. The teaching program using instructional coaching

Trial of coaching science

Instructional coaching had been embedded successfully in the school culture for the facilitation of professional development. As part of the school's Annual Implementation Plan, a commitment to implementing instructional coaching for improving the teaching of literacy and numeracy had been implemented by resourcing time to release teachers for reflection with the coach and for other teachers to observe their teaching. The successful culture of coaching in the school has supported the researcher, who is also a staff member at the school, to expand coaching beyond the existing literacy and numeracy coaching program. During the final school term of 2013 the researcher implemented a trial of coaching in Science.

With the Principal's approval, the instructional coaching was offered to the year-4 and year-5 teachers prior to Stella volunteering for this study. The teacher volunteered, in consultation with the Principal, as a subject who identified herself as having an interest in teaching Science and also an interest in coaching. Given that one of the goals of instructional coaching is to enable teachers to implement instructional practices that respond directly to teachers' burning issues (Knight, 2009), it was important for Stella to be a willing and enthusiastic participant with a desire to develop her capabilities teaching Science.

Teaching science inquiry skills using GRR

The topic was a Primary Connections (Australian Academy of Science, 2012) life and living unit on plants. The purpose of this study was to develop innovative learning activities designed in accordance with the framework for GRR (Fisher & Frey, 2008) to explicitly teach the Science Inquiry Skills identified as being important for learning in Section 2.1.6, through the four categories of scientific literacy distilled from the literature.

Table 3.3 illustrates an elaboration of Science Inquiry Skills that were the focus of explicit teaching episodes in the GRR and provided a framework for collecting evidence of the teacher's Science pedagogy as well as students' learning outcomes.

Table 3.3

Elaboration of Science Inquiry Skills for teaching in the GRR

Science Inquiry Skills	Evidence of learning What I'm Looking For (WILF)
Questioning Students: Ask and answer questions	How you ask and answer questions to: • Expand your knowledge • Seek solutions • Clarify information
Investigating Students: Conduct experiments using fair testing procedures	How you make the test fair test by: • Cows – change one thing • Moo – measure or observe something • Softly – keep everything else the same
Observing Students: Make and record observations	How you: • Use your senses to observe and gather information accurately • Accurately represent observations
Measuring Students: Make accurate scientific measurements	How you make: Accurate scientific measurements
Data analysis and interpretation Students: Analyse and record data	How you: • Look for patterns and relationships in the data • Use scientific language to explain possible reasons for data • Compare data with your prediction
Communicating Students: Communicate scientifically	How you: • Use scientific vocabulary to communicate understandings • Use a concept map to organise thinking

As explained previously a trial of instructional coaching in Science has laid the foundation for the study. Resources that were developed by the researcher and used in the trial to support the implementation of the GRR framework included: lesson development; digital resources, (i.e., PowerPoint presentations for lessons, Ed Studio); professional development resources; posters; student worksheets.

Table 3.4 illustrates the way in which Science Inquiry Skills became a focus for teaching in each lesson. By identifying the learning outcomes (WALT: We are learning to) and strategically planning the sequence of learning in each lesson prior to implementation, Stella determined which Science Inquiry Skills were required for students to engage in the science inquiry process as well as the best possible placement within the Life and Living science unit for teaching each skill.

Table 3.4

Elaboration of Science Inquiry Skills taught in the life and living unit

Year-4 Science Unit	
Lesson 1 SIS Focus	WALT:
What goes where?	• BIG IDEA – 'How Does Time Affect Me?'
Observing	• recall the basic needs of living things.
	• represent stages in the life cycle of flowering plants
ENGAGE	• label parts of a plant: root, stem, leaves, flowers, fruit.
	• discuss ideas and questions for a TWLH chart
	• create a list of words that relate to plants and animals
Lesson 2 SIS Focus	WALT:
What's in a seed?	• What have we learnt so far? Review TWHL Chart
Questioning	• Using the skill of Questioning to discover what we know about seeds
	• Use 'We Do' strategy to record observations of a dry bean seed
EXPLORE	• Use 'You Do' strategy to record observations of a soaked bean seed
	• label a diagram of the inside of a bean
	• Update TWLH Chart
	• Review word wall
Lesson 3 SIS Focus	WALT:
Bean seed germination	• BIG IDEA – 'How Does Time Affect Me?'
Observing and Questioning	• explore packaged bean seeds
	• read and discuss a procedural text for a bean seed germination activity

EXPLORE	• work in teams to prepare bean seeds • make ongoing observations and recordings of bean seed germination • Review TWHL chart
Lesson 4 SIS Focus Observing, Investigating and Communicating EXPLORE	WALT: • Review TWHL chart • Review Observation skills • Make observations of bean seed growth • Review Investigation Procedures • Review Communication skills • Review word wall
Lesson 5 SIS Focus Making sense of communicating in science EXPLAIN	WALT: • Review Communicating in Science • Making Observations • How does sunlight affect plant growth? • How do soil types affect plant growth? • How does temperature affect plant growth? • Review TWHL chart • Review Word Wall
Lessons 6 & 7 SIS Focus Measuring in science ELABORATE	WALT: • Review measuring in science • Review ways of recording measurements • Fair testing and measuring • Make and record measurements • Review TWHL chart • Review word wall
Lesson 8 SIS Focus Analysing data in science EVALUATE	WALT: • Review investigation • Discuss results of investigation from each group • Consider ways of analysing data in science • Record in science journals • Review TWHL chart

3.3.4. Data collection methods

Data sources for the case study research were organised around three main foci:

1. The teacher participant;
2. The student participants;
3. Gradual release of responsibility model.

Teacher data sources

It was important to use the GRR framework to inform data sources in relation to the teacher's Science pedagogy to answer the research questions:

1. What strategies does the teacher use to implement Science Inquiry through GRR practices in a year-4 Science class?
2. What affordances/constraints does the teacher identify in using these strategies?

In keeping with the essence of data collection aligned with qualitative case study, several methods of data collection were implemented. These included a range of teacher data sources:

1. Teacher planning documents: Stella modified the Primary Connections Unit, Plants in Action (Australian Academy of Science, 2012), and referred to the Australian Science Curriculum (Appendix 1) to plan the sequence of learning. She identified the learning outcomes students were expected to achieve and planned to explicitly teach the Science Inquiry Skills (questioning, investigating, observing, measuring, analysing data and communicating findings).
2. The student pre-test (Appendix 2) was implemented to determine the students' prior understanding of the scientific concepts they were expected to learn as well their prior learning experiences using the Science Inquiry Skills.
3. PowerPoint presentations: Stella prepared a PowerPoint presentation of approximately 10 slides for each of the eight lessons. The GRR phases were explicitly identified on the slides.
4. Video and audio recordings of the eight weekly one hour science lessons: These provided evidence of how GRR instructional practices

were implemented by the teacher. Two cameras were positioned in the classroom. One was at the front and the other was at the back of the classroom. They were operated by the researcher. Both cameras were focused on the whole class, however, while students collaborated in science teams one camera was used to zoom in on Stella as she circulated around the class. An audio recorder was placed in the middle of each science team.

5. Photographs of notes, illustrations created by the teacher on classroom whiteboards during lessons: These included students working in science teams and student artefacts, for example, plants growing in pots.
6. Informal interviews with the teacher: Throughout the eight week science unit the researcher conducted informal interviews with the teacher, asking probing questions into the practices and pedagogical reasoning in relation to concrete examples embedded in the actual practice of the teacher participant. For example, in seeking to explore the teacher's formative assessment the following questions were asked:

"How did you monitor students' within the phases of the GRR?"

"How does formative assessment help you make decisions about what you're going to teach?"

In summary the teacher data sources sought to discover what the teacher did, what hindered her, what assisted her, and what response there was from the students.

7. Teacher's reflective journal. The teacher was provided with four questions to guide her reflective journal entries. The teacher's reflective journal provided a rich source of evidence for understanding conceptions of the phenomenon (the teacher's GRR pedagogy teaching SIS). Stella made entries into a reflective journal after teaching each one hour science lesson which focused on a specific Science Inquiry Skill (observing, questioning, investigating, measuring, data analysis and interpretation or communicating).

The following questions provided a framework for collecting teacher reflections.

Question 1.

What **strategies** do you use to implement GRR practices to teach for teaching Science Inquiry Skills? ________________ (name of skill)

(You can attach any supporting documents, for example, worksheets, formative assessments. Please make a note of any ideas that you think would be useful for other teachers using the GRR to teach Science Inquiry Skills. This can be in note form and is not meant to take up much of your time. Add additional dates to suit where required).

I do it:

Date

We do it:

Date

You do it together:

Date

You do it alone:

Date

Question 2a.

What **constraints** do you identify when teaching students ___________ Science Inquiry Skill using the GRR? Are there any **limitations**? (Consider what you think other teachers using this method would like to know. Make your own reflective notes).

I do it:

Date

We do it:

Date

You do it together:

Date

You do it alone:

Date

Question 2b.

What **is positive** about using the GRR when teaching students ___________ Science Inquiry Skill using the GRR?

(Consider what you think other teachers using this method would like to know).

I do it:

Date

We do it:

Date

You do it together:

Date

You do it alone:

Date

Question 3.

What **outcomes** related to SIS do the students (individuals/ whole class) make? (Note any observations that you consider are significant. Evidence of students' learning outcomes will also be evident in video/audio recordings, science journals, formative/summative assessments and PAT Science. Note any progress that the students are making towards achieving the WILF goals).

Student data sources

Data sources providing evidence of students' learning outcomes sought to reveal what responses there were from the students to answer the research question:

What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model? These included:

1. Video and audio recordings of the eight one hour lessons: Two cameras were positioned in the classroom. The two cameras were focused on the whole class, however, while students collaborated in science teams one camera was used to zoom in on the student focus group of the study

(Queensland). An audio recorder was placed in the middle of each science team. There were eight science teams with 3 to 4 students in each.

2. Individual student science journal: This was completed during each lesson. Students were required to complete an end-of-unit investigation in their science journal. Examples from Queensland students' science journals are provided in Chapter 5.
3. Individual student science reflective journals: These were completed weekly. An example of a student's reflective journal is provided in Appendix 3. At the end of each week students made an entry in a reflective journal to record metacognitive thinking of their learning.
4. Individual and group graphic organisers: These were teacher made and also sourced from the Primary Connections Unit: Plants in Action (Australian Academy of Science, 2012). The graphic organisers were completed individually or by the whole group, depending on the learning intent.
5. Individual post-teaching survey (Appendix 4): Each student completed the Science Inquiry Skills survey at the end of the eight week science unit. These were analysed for evidence of students' awareness of their own learning of Science Inquiry Skills and scientific conceptual knowledge and understanding and; students' affective experiences of learning science.

Additionally, the "What I'm Looking For" (WILF) framework (Table 3.3), highlights the focus for student data collection and analysis to determine students' learning outcomes. The teacher and researcher paid particular attention to the extent to which students demonstrated, *What I'm looking for* … (WILF) goals. The teacher kept a reflective journal on students' activities and learning outcomes in Science. The WILF framework together with student data sources provided valuable insight into what outcomes were achieved by students.

There are many ways to monitor students' understanding. The researcher (in the role as instructional coach) had modelled some of them during the trial of science coaching, however, for this case study the year-4 teacher determined these data sources. Teacher-student dialogue offered one way to monitor progress and facilitated formative assessment in each phase of the GRR. Teacher-student dialogue providing evidence of Stella monitoring student progress was transcribed from audio and video recordings and is reported in Chapters 4 and 5.

Gradual release of responsibility framework in relation to data collection

Evidence of how the teacher implemented the GRR for teaching Science Inquiry Skills was collected during research. There are four phases of learning in the GRR framework. These are: *I do it; We do it; You do it together; You do it alone* (Figure 2.1). This model of instruction gradually releases the responsibility of learning throughout these four phases from teacher to students. Table 3.5 provides an elaboration of teacher and student data sources in relation to the GRR model.

Table 3.5

Elaboration of teacher and student data sources using GRR model

Phase of GRR model	Data sources
Before GRR	Students' PATScience assessments. Students' pre-test of knowledge (Appendix 2).
I do it (teacher explanation and demonstration)	Video and audio recordings of dialogue in the "I do it" phase of instruction in each lesson. A range of teacher planning documents that provided evidence of how GRR instructional practices (lesson PowerPoints, unit planning documents). Formative assessments designed by the teacher. Photographs of notes and illustrations created by the teacher on classroom whiteboards during lessons.

	Photographs and audio recording of teacher-student discussions. Informal interviews with the teacher to determine what worked well and what didn't. Teacher's reflective journal.
We do it (teacher-student collaboratively)	Video and audio recordings of teacher-student and student-student dialogue. Students' science journals displaying evidence of scientific literacy. Students' graphic organisers completed throughout the Science Unit. Teacher's reflective journal. Semi-structured interview with teacher to determine how students were monitored.
You do it together (collaboration in groups)	Video and audio recordings of teacher-student and student-student dialogue. Teacher semi-structured interview to determine what worked well and what didn't work. Formative assessments designed by the teacher. Students' end of unit investigation. Teacher's reflective journal. Students' science journals displaying evidence of scientific literacy. Students' reflective journals displaying evidence of scientific literacy (Appendix 3).

You do it alone (independent)	Video and audio recordings of teacher-student and student-student dialogue. Teacher semi-structured interview to determine what worked well and what didn't work. Students' end of unit investigation. Students' science journals displaying evidence of scientific literacy.
After GRR	Students' PATScience assessments. Students' post-teaching survey (Appendix 4).

3.3.4. Analysis of teacher data sources

Data analysis followed procedures recommended for case-study (Creswell, 2007), including interpretation of the data, establishing patterns, and developing assertions. The purpose of data analysis was to develop an understanding of how and why the teacher applied what she learned in the trial of instructional coaching in science to her classroom teaching, which laid the foundation for the case study. Analysis of teacher data sources proceeded through four stages as shown in Figure 3.1

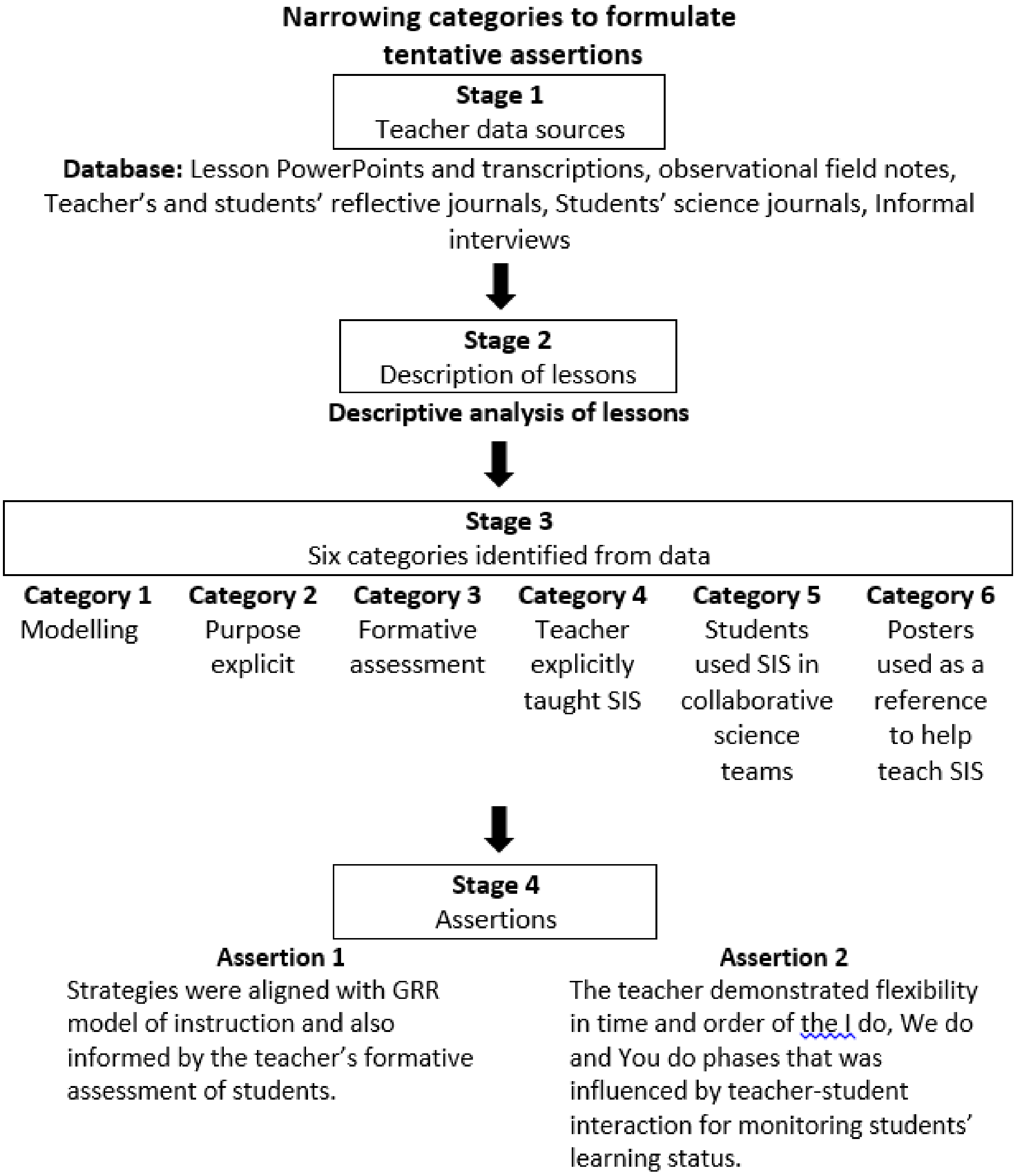


Figure 3.1 Analysis of teacher data sources

Stage one: Data collection with note taking and beginning analysis

Data analysis was progressive with data collection (Lincoln & Guba, 1985). Holistic Coding was used to investigate broad topic areas as a first step of data analysis (Saldaña, 2013). After a first review of the data corpus with Holistic Codes applied, "all the data for a category was brought together and examined as a whole before deciding upon any refinement" (Dey, 1993, p.105). While video and audio recording the science lesson each week, I recorded my initial impressions, some of which later emerged as the six categories which were subsequently refined as tentative assertions. The technological resources provided by the teacher were useful as I could review each lesson by viewing her PowerPoint presentation as well as my video recordings and then cross-checking my impressions with entries that she recorded in her reflective journal. A set of supporting questions, outlined above, matching the main research questions, was provided to the teacher to guide her journal reflections and served as a filter for interpreting the data (Saldana, 2013). Thus, her reflections were grouped according to the six Science Inquiry Skills (observing, questioning, investigating, measuring, data analysis and interpretation and communicating) as well as the phases of the GRR (I do it, We do it, You do it together, You do it alone), which provided insight into how and why she used strategies and what constraints were identified. Subsequently, I colour coded and labelled all of the propositional clusters (Appendix 5). I used the information gathered from my initial analysis of the lessons and the journal reflections to guide my questioning and informal interviews with the teacher throughout the study. This enabled me to search for recurrent themes or categories and identify key patterns emerging.

Stage two: Description of lessons

At the conclusion of teaching the unit of work the teacher finalised the reflective journal of her experiences in the classroom; the reflections were the source of my initial search to uncover emerging themes or categories. I copied all of the propositional clusters (Appendix 5) into a Microsoft Excel spreadsheet. This allowed me to sort the clusters by category (Saldana, 2013).

Stage two of data analysis was aided by having the video and audio recordings of the lessons. Many weeks of manually transcribing the eight science lessons and looking for recurrent themes or categories enabled me to identify the key patterns emerging. A general analysis of the time spent on each GRR phase (I do it, We do it, You do it together and You do it alone) and the level (extent) of teacher versus student talk, that is, how much time was spent in direct transmission of ideas (explicit teaching), transactional time (teacher questioning /students responding), and student interactive time (students working in small groups) helped me to further refine the emerging themes (Appendix 6).

Stage three: Emergence of categories

I coded the data according to repeated key words and phrases. I reread passages and began discovering links and identifying patterns between the emerging categories. For example, I found that, across categories, there was evidence of science literacy as a focus for learning. Similarly, determining students' knowledge and understanding of the science inquiry skills guided the ordering of the GRR phases in each lesson, and lack of time constrained such application. These realisations caused me to revise and recode some of the data in light of the connections I was noticing. I considered how these emerging themes related to my research questions. A further revisiting of the data corpus followed to search for confirming and disconfirming evidence. Six categories or themes emerged by the end of stage three data analysis. These initial categories were refined further to give assertions:

1. Modelling

2. Purpose explicit

3. Formative assessment

4. Teacher explicitly taught SIS in "You do it" and "We do it" phases

5. Students used SIS in collaborative science teams

6. Posters were used as a reference to help teach SIS

Stage four: Tentative Assertions

During the construction of the tentative assertions I continued to search for evidence in the coded data for the recurrent themes that were emerging. At times I would need to review the original themes distilled from the literature, code more data and re-write the emerging themes. Throughout the process, I discussed emerging themes and tentative assertions with my supervisory team and also with the teacher.

3.3.5 Analysis of student learning outcomes

A modified SOLO-taxonomy was used for examining the quality of students' SIS in terms of levels or stages. In doing so, selected transactions of teacher-student and student-student collaborative science dialogue in the video recordings and audio recordings were analysed. The analysis was based on the Elaboration of SIS and the SOLO-taxonomy described by (Biggs & Collis, 1982) and later developed by them (1991), which was modified for this study (Table 3.5). As the SOLO model utilises the responses provided by learners during dialogue, this taxonomy was used to examine transactions of student-student and teacher-student collaborative science dialogue in the "You do it together" phase of selected lessons to assess the quality of responses from students. Additionally, it was applied to students' science journals and reflective journals. Modified versions of the SOLO-taxonomy have also been used by researchers interested in how students learn and what learning means. For example, Eskilsson (2008) studied the quality of lower secondary students' discussions during lab-work in chemistry, and (Panizzon, 2003) investigated students' understandings of diffusion.

In modifying the SOLO-taxonomy to analyse students' responses, it was important to look closely for evidence of scientific conceptual knowledge as well as Science Inquiry Skills as illustrated in the Elaboration of SIS (Table 3.3) to analyse a range of students' data sources. Table 3.5 (below) illustrates the modified SOLO categories that include specific reference to the SIS drawn from the Elaboration of Science Inquiry Skills. No categories corresponding to pre-structural and extended abstract were used as these categories are irrelevant in this study. Such responses categorised as pre-structural are not relevant, since they do not show how students use their science knowledge or skills. Additionally, extended abstract responses that apply to students formulating generalised principles were not evident in this study. In some of the other categories sublevels have been formulated to account for responses that do not fit perfectly into a level. Transitional responses have been named according to the level from which the response is transitioning; for example, U2 is in between uni-structural and multi-structural. This may occur when a student is reaching the next level, but does not quite respond at that level. All statements from the students originate from student-student or teacher-student dialogue.

Table 3.7

Categories used in this study according to a revised SOLO-taxonomy

Category in the present study	SOLO-category by Biggs and Collis (1982, 1991)
U1/ describes/uses one part of the SIS, e.g., makes an observation, asks a simple question, follows a simple procedure, e.g., the plant has green leaves. U2/ uses one part of the SIS and mentions relevant science concepts, e.g., the seeds are beginning to grow.	Uni-structural One relevant aspect Identify, name, follow simple procedure
M3/ uses more than one SIS in a relevant way but no integration, e.g., measures the height of a bean plant and makes observations about the length and colour of roots, e.g., the plant has grown 2 centimetres and has long white entwined roots. M4/ discusses or describes more than one relevant science concept but does not integrate concepts conclusively, e.g., the water made the seed grow and it got bigger.	Multi-structural Several relevant independent aspects Combine, describe, list, perform serial skills
R5/ integrates two or more science concepts *and* SIS to argue, explain, evaluate, justify, compare or criticise, e.g., this plant in the garden soil has grown the best (refers to plant growth graph) because it has absorbed the nutrients from the soil.	Relational Integrated into a structure Conclude, analyse, apply, ague, justify, critisise, explain causes, reflect, compare/contrast, relate

The focus of this study is students' use of Science Inquiry Skills. This revised version of the SOLO-taxonomy (Table 3.5) makes it possible to determine information about the students' application of Science Inquiry Skills during an investigation and the quality of students' knowledge in the science conceptual area. Selected transactions of teacher-student collaborative science dialogue in the video recordings and audio recordings were analysed. The analysis was based on the Elaboration of SIS for teaching with the GRR (Table 3.3) and the modified SOLO-taxonomy (Table 3.5). An example of the analysis is provided in Appendix 7. A complete analysis of student learning outcomes using the modified SOLO-taxonomy can be found in Chapter 5.

Research question three is, "What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model?" Therefore, in an attempt to document the effect of teaching SIS using the GRR throughout the Life and Living unit on students' learning outcomes, a rubric that combined the modified version of the SOLO-taxonomy and Elaboration of SIS was developed and used as the analytical framework for analysis of students' written and oral learning outcomes in this study. The rubric identifies five SOLO levels for each Science Inquiry Skill with uni-structural being the lowest level and relational being the highest level. For example, for the SIS questioning, a uni-structural response would involve students asking or answering questions about science procedures. Whereas the higher relational level would require students to ask and answer questions and make reasoned conclusions relating science concepts and procedures. The SIS Modified SOLO-taxonomy Rubric (Table 3.6) was applied to student data sources including students' science journals and reflective journals and teacher-student and student-student collaborative science dialogue in the "You do it together" phase of instruction.

It is important to note that in this study the SIS Modified SOLO-taxonomy Rubric (Table 3.6) was developed and applied at the conclusion of instruction, however, it also has potential to play a role in formative assessment of students' responses throughout the teaching-learning cycle. Formative assessment provides feedback to teachers on the effect of their pedagogy and informs future instruction but also has a role in providing effective feedback to students about their own learning. A recommendation for using the Modified SOLO-taxonomy Rubric for formatively assessing students' written and oral responses throughout the teaching-learning cycle is discussed in more detail in Chapter 6.

Table 3.8

SIS Modified SOLO-taxonomy Rubric

Science Inquiry Skills	Evidence of learning What I'm Looking For (WILF)	SOLO-category U1	SOLO-category U2	SOLO-category M3	SOLO-category M4	SOLO-category R5
Questioning Students: Ask and answer questions	How you ask and answer questions to: • Expand your knowledge • Seek solutions • Clarify information	Ask or answer questions about science procedures	Ask and answer questions about science procedures and mention relevant science concepts	Ask and answer questions about science procedures and discuss relevant science concepts	Ask and answer questions about science concepts and procedures; attempt to make conclusions	Ask or answer questions and make reasoned conclusions relating science concepts and procedures
Investigating Students: Conduct experiments using fair testing procedures	How you make the test fair test by: • Cows – change one thing • Moo – measure or observe something • Softly – keep everything else the same	Follow steps in fair testing procedures	Identify a variable; follow steps in fair testing procedures	Identify some variables and follow steps in fair testing procedures	Identify dependent and independent variables and conduct fair testing procedures	Conduct an experiment using fair testing procedures; explain reasons a test is fair or not
Observing Students: Make and record observations	How you: • Use your senses to observe and gather information accurately • Accurately represent observations	Make and record an observation	Make and record an observation and mention relevant science concept	Make, record and compare observations using knowledge of relevant science concepts	Represent and interpret observations using knowledge of relevant science concepts	Interpret and compare observations scientifically and make connections with real world examples
Measuring Students: Make accurate scientific measurements	How you make: • Accurate scientific measurements	Measure an object	Make and record measure-ments	Make accurate scientific measure-ments and record results in a table	Make accurate scientific measure-ments and record results in a tabland graph	Compare and contrast scientific measure-ments and make reasoned conclusions
Data analysis and	How you:	Record data	Follow a	Record	Interpret	Analyse data;

interpretation Students: Analyse and record data	• Look for patterns and relationships in the data • Use scientific vocabulary to explain possible reasons for data • Compare data with your prediction		procedure to accurately record scientific data	accurate scientific data; look for patterns and relationships	patterns and relationships in the data using scientific vocabulary	scientifically explain patterns and relationships; compare results with prediction
Communicating Students: Communicate scientifically	How you: • Use scientific vocabulary to communicate understandings to others • Reflect on how your ideas have changed	Describe one relevant aspect of a science procedure or concept with others	Describe an aspect of a science procedure and mention relevant science concepts	Discuss or describe science procedure and relevant concepts with scientific vocabulary	Explain procedure and relevant concepts with scientific vocabulary and attempt to make conclusions	Communicate scientifically to make reasoned conclusions, analyse, apply to real world examples, argue, justify, criticise, explain causes and reflect on how ideas have changed

Figure 3.2 provides an example of analysis of the quality of one student's written outcomes in this study using the SIS Modified SOLO-taxonomy Rubric. This example is further discussed in the lesson analysis of student outcomes (Section 5.3.5).

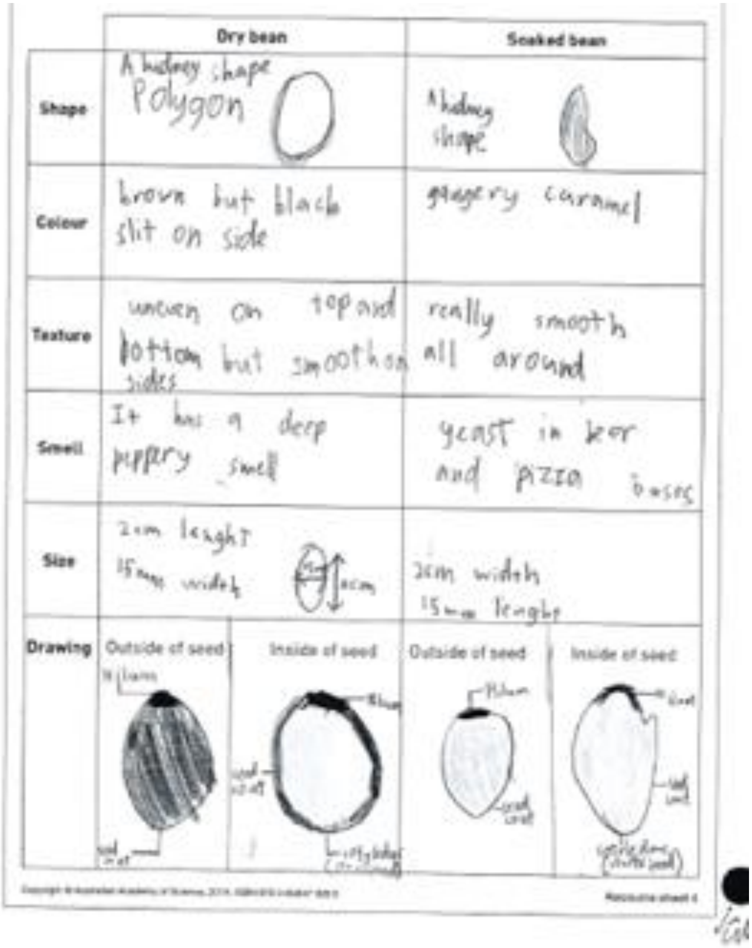
SOLO Category	"Queensland" Student Graphic Organiser
1. M3 2. M3 3. M3 4. U2 5. M3 6. M3	

Figure 3.2 Seed observation record by Peter (Primary Connections, 2012)

3.3.6 Focus science team for study "Queensland"

There were eight science teams altogether, each named with a State of Australia. Within the scope of this study analysis of the data from all eight science teams was unwieldy, therefore, science team, "Queensland" with Peter, Eliza, Polly and Christopher was selected as a focus group for data analysis revealing evidence of students' learning outcomes. The teacher grouped the students in the year-4 science teams according to ability as determined in a pre-test (Appendix 2). Three of the four students in the focus group "Queensland", scored above average on the pre-test administered prior to teaching the Science Life and Living Unit. This group was chosen as the focus group due to these results and the interesting results they achieved in the PATScience (Table 3.7).

Table 3.7

PATScience scores for Queensland science team

Student	Percentile Jan	Stanine Jan	Percentile July	Stanine July
Peter	88%	7	81%	7
Polly	51%	5	93%	8
Christopher	59%	5	23%	4
Eliza	36%	4	81%	7

Standardised testing is a highly controversial and well debated topic. One advantage of standardised testing is its consistency, which permits more reliable comparison of outcomes across all test takers, allowing comparison of students located in various schools, districts, and states. The Australian Council for Education Research (ACER) Progressive Achievement Tests in Science (PATScience) is a nationally normed test to assess student achievement in scientific understanding from Years 3 to 10. The test questions are designed to assess science knowledge, scientific literacy and understanding of scientific principles, as well as their application (Martin et al., 2009). The PATScience tests' norming sample (2008) included a large sample of schools (86) and students (over 7000) from all States and Territories of

Australia. The percentile rank shows the percentage of students from lowest achievement to highest achievement with 50% being the mean of the normal distribution. The norm-referenced stanine scale of PATScience is sorted into nine categories including 1 to 9. Stanine scores have a mean of 5 and a standard deviation of 2 stanines. The mean of the normal distribution occurs at the centre of stanine 5 (Martin, et al., 2009). Stanine scores are useful in providing general achievement levels of individuals or groups as illustrated by the following descriptors (1 very low; 2 low; 3 below average; 4, 5, 6 average; 7 above average; 8 high; 9 very high).

PATScience was administered prior to implementation of the year-4 Life and Living unit at the end of term one and again in term three after all the teaching had been finished. Descriptive statistics was applied to the PATScience assessment to determine overall trends and the distribution of data. Themes from the qualitative data analysis were triangulated with trends identified in quantitative data analysis of the PATScience.

3.4 Ethical considerations

The research was undertaken in accordance with the Queensland University of Technology Code of Conduct for Research (MOPP D/2.6), and the National Statement on Ethical Conduct in Human Research (2007). Reference was made to QUT policies in relation to the conduct of research involving human participation, in particular D/6.2 Research involving human participation. Ethical clearance by QUT Human Research Ethics Committee (UHREC) for a "Negligible/Low Risk" activity was granted (Approval Number: 1400000287). The research also complied with the Queensland Government requirements for conducting research in state education sites (DETA, 2004). Permission was obtained from the teacher, students and their parents/caregivers to be audio and video recorded during science lessons. Additionally, consent was obtained from participants for use of images (including photos and video recordings) in professional development presentations for teachers as well as conference presentations.

Participants' ethical clearance and considerations

Research informed the consent mechanisms with adults and students. Chapter 2.2 "General Requirements for Consent" and Chapter 4.2 "Children and Young People" provided guidance regarding consent of the child only under certain conditions, for example, he or she is mature enough to understand and consent when research is no more than low risk. It was recognized that consent must be sought from students and parents.

Potential issues collecting data in a classroom setting were considered as described in the Research Ethics Unit Guidance Document for Human Research: Research Data Collection in Classroom or Lecture Theatres UHREC Ref No: 001/2010. To avoid disclosing identities of participants and school, pseudonyms were used.

Reimbursing participants for their time and effort is an accepted, appropriate and ethical practice. In keeping with the principle of reciprocity, the researcher provided professional development programs for the entire staff at the school in explicit teaching Scientific Inquiry Skills, as well as incidental professional support when requested. The students were provided with support in developing an open inquiry for the school's Science Expo that reinforced skills taught in class.

3.5 Limitations

O'Leary (2004) proposes criteria for judging the quality of research design. Each of O'Leary's questions is addressed to assess potential problems that may arise during research.

Have subjectivities been managed?

Remaining neutral to avoid bias within results and conclusions is potentially a problem for the researcher when assuming the multiple roles of instructional coach, teacher and researcher. It would be very easy to collect data that exclusively supported one point of view while dismissing data that supported results to the contrary. Using multiple sources of data has helped to overcome this problem.

Are methods approached with consistency?

Again, the teacher-researcher is faced with the problem of dependability caused by the demand of wearing two-hats at once, “teacher” and “researcher”. Attention was given to implementing systematic, well-documented methods designed to account for research subjectivities.

Has “true essence” been captured?

While multiple truths are believed to exist, the challenge lies in understanding and describing the phenomenon (what the teacher did, what hindered and assisted her, and what response there was from the students?) in depth in a manner that is “true” to the experience.

Are findings applicable outside the immediate frame of reference?

Yin (2009) recognises that external validity has been a major barrier in doing case studies. The constructivist ontology of multiple realities that are socially constructed and specific in nature to the context also causes problems in relation to generalisations beyond the immediate case study. While generalisation is not automatic, this research aimed to provide an important contribution that demonstrated a teaching model that can be used in another setting or applied to another year level. Potential threats to validity due to bias or other problems explained previously, may limit transferability.

Can the research be verified?

Single sources or evidence in qualitative studies can limit the ability of the researcher to prove how they arrived at their conclusion. Yin (2009) explains, “Any case study finding or conclusion is likely to be more convincing and accurate if it is based on several different sources of information, following a corroboratory mode” (Yin, 2009, pp. 115,116). In this case study, data from multiple sources were collected and analysed. Furthermore, the research methods were sufficiently explained to allow other researchers to audit the original research process and determine the credibility and value of research.

3.6 Conclusion

This chapter has argued the appropriateness of the case study methodology to study a primary teacher's experiences teaching Scientific Inquiry (SI) using the GRR model of instruction. The chapter has demonstrated how the research design and approach complemented the theoretical perspectives of the study.

Case study design was justified as an appropriate method to investigate the research aim and research questions of the study. The case study approach has permitted in-depth inquiry into the phenomenon using a range of data sources and adherence to strict ethical procedure within the classroom context of the research. The investigative methods have facilitated comprehensive description of interpretations, which has potential for adding significant contribution to the field of science education from the perspectives of both teacher education and teaching Scientific Inquiry.

Chapter 4 **Teaching Results**

4.1 Introduction

The purpose of my study is to explore and explain how a year-4 teacher implemented the GRR model of instruction to teach Scientific Inquiry Skills (SIS) in the classroom. The three main research questions posed were:

1. What strategies does the teacher use to implement GRR practices in a year-4 Science class?
2. What constraints/affordances does the teacher identify?
3. What outcomes do students achieve?

This chapter provides an in-depth analysis of the teacher data sources to reveal how the teacher implemented the GRR model of instruction for teaching Science Inquiry Skills to answer research Question 1. Furthermore, data analysis of the teacher's reflections of GRR instructional practices and students' learning outcomes provided critical insights for answering research Questions 2 and 3.

Additionally, the analysis examines how Pearson and Gallagher's Gradual Release of Responsibility model played out in the instructional contexts of the study. An effective model for the GRR (Pearson & Gallagher, 1983, p. 29; Zeyer & Kyburz-Graber, 2012) proposed by Fisher and Frey (2008) moves from modelled to guided instruction, followed by collaborative learning and finally independent experiences (Figure 4.1). This structure was used for implementing the GRR to teach Science Inquiry Skills in the year-4 classroom.

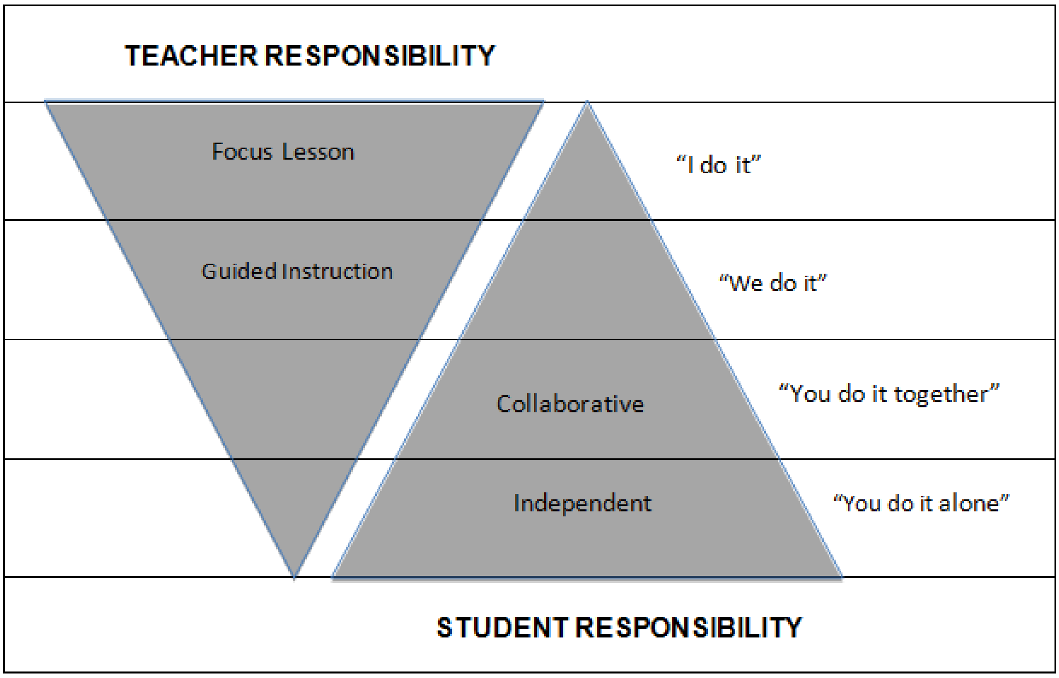


Figure 4.1 A structure for successful instruction (Fisher & Frey, 2008)

An analysis of data from the classroom observations, informal interviews and reflective journal entries and students' artefacts suggested that in the classroom setting, the order of the instructional phases, I do it, We do it, You do it, was influenced by the context of the science unit and by the teacher's formative assessment of individual students' learning and subsequent goals for students' learning, both implicit and explicit. Therefore, I will present illustrations of the teaching that occurred in the classroom setting to provide a model that describes the GRR process for teaching a year-4 Science unit that emerged from the data, with specific attention to how planning and instructional procedures changed over time.

The findings of the study are presented and analysed with each section providing snapshots of the data that were analysed and the conclusions that such analysis facilitated.

4.2 GRR Strategies for teaching SIS

Research question one involved analysing the teacher's reflections of each lesson and also transcriptions of audio and video recordings of the eight lessons in order to describe the strategies used by the teacher. The analysis has led to the development of two assertions relating to the case being studied, which answer research Question 1: What strategies did the teacher use to implement GRR practices in a year-4 science class? These assertions are:

1. Strategies were aligned with the GRR model of instruction and also informed by the teacher's formative assessment of students.
2. The teacher demonstrated flexibility in time and order of the GRR phases that was influenced by teacher-student interaction for monitoring students' learning status.

The two assertions related to the strategies used for implementing GRR practices in a year-4 science classroom are discussed in this chapter. The first assertion deals with the establishment of a clear learning purpose for each lesson, referred to as WALT (We are learning to), that was relevant to the context of the Life and Living unit and was also informed by students' understanding of Science Inquiry Skills. This lead to a major finding presented in Assertion 2 that the teacher planned a flexible approach when implementing the phases of the GRR; 'I do it', 'We do it', 'You do it' that was influenced by teacher-student interaction for monitoring students' learning status.

4.3 ASSERTION 1: Flexible Lesson Structure

Strategies were aligned with the GRR model of instruction and also informed by the teacher's formative assessment of students.

I will begin by setting the scene with a short description of the science unit taught. In order to teach a science unit, the teacher's first step is to plan the unit. In this case study the teacher used a Primary Connections Science Unit (Australian Academy of Science, 2012) and adapted it so that Science Inquiry Skills were incorporated as a major focus for explicit teaching in each lesson. In the term-2 Life and Living science unit students investigated life cycles and examined their dependence on the environment. They developed an appreciation of plants as they investigated the process of germination, the stages in a plant's life cycle and what plants need for growth. They were required to identify investigable questions, implement a fair test and predict likely outcomes from their investigations. This was the second science unit taught during the year. In total, four units were taught throughout the year; one each term. The lessons consisted of a weekly one-hour lesson each Tuesday afternoon followed by another forty-five minute lesson that allowed time for the teacher to finalise the lesson goals. The follow-up lesson was scheduled on a separate day. It was planned to video and audio record the weekly one-hour science lesson for the first five weeks of the school term (Lessons 1 to 5). On the sixth week a double lesson that spanned two one-hour sessions was video and audio recorded (Lessons 6 and 7) and the final lesson occurred in the ninth week of the school term (Lesson 8). This provided me with a solid database, along with student artefacts and the teacher's planning documents, for analysing how the teacher implemented the GRR to teach the science unit (Appendix 8).

4.3.1. Planning the sequence of teaching SIS

The planning that preceded teaching the science unit, revealed through informal interviews with the teacher, was important for developing a unit that followed the GRR model, with a focus on teaching SIS. First, an initial goal for the teacher was to completely understand the Life and Living science unit. The teacher scrutinised the proposed sequence of learning to identify essential knowledge and skills necessary for students to learn in each lesson. In doing so, she also made reference to the Australian Science Curriculum for year-4 (Appendix 1) in order to align the teaching with curriculum intent.

Second, she thought about learning in multiple ways; the first related to the scientific understanding students were expected to develop and the students' prior understanding of the scientific concepts; the second considered the science inquiry skills necessary for students to engage in the science inquiry process and their prior learning experiences using the skills; and the third involved structuring of the learning environment or social context within which students were expected to engage in learning about science.

A pre-test (Appendix 2) was administered initially to determine students' prior understandings. A table (Appendix 8) illustrates the way in which science inquiry skills became a focus for teaching in each lesson. By identifying the learning outcomes (WALT: We are learning to) and strategically planning the sequence of learning in each lesson prior to implementation, Stella determined which Science Inquiry Skills were required for students to engage in the science inquiry process as well as the best possible placement within the Life and Living science unit for teaching each skill.

The following sections provide evidence from transactions of lessons and the teacher's reflective journal revealing how Stella structured the learning environment using phases of the GRR that supported the scientific understanding the students were expected to develop whilst simultaneously explicitly teaching Science Inquiry Skills. It is important to note that the students were familiar with the language of the GRR, "I do it", "We do it", "You do it together" and "You do it alone". As explained in Chapter 3, the GRR instructional model underpins the school's pedagogical framework, and as such, is used for teaching all learning areas including science. Posters of the GRR phases were displayed in the classroom and Stella also included the names of the phases on the lesson PowerPoints to prompt students.

4.3.2. Teaching the SIS of ***observation*** with modelling and think-aloud strategies in lesson one

In lesson one the students were required to make observations of parts of plants using a magnifying glass (see Appendix 8 for Lesson Outline). A mystery box containing a number of items (plants) that were linked together in some way was given to each group (Figure 4.3). The task, which generated rich discussions, required students to observe the items in the mystery box, think of what they knew about the items and how they were linked. The teacher circulated among the science teams to scaffold students and reflect on their use of the skill of observation in order to plan future learning experiences.

Transaction 1: Stella's modelling of the SIS of *observation* using think-aloud in the "I do it" phase.

Stella I'm going to give you an example of what we're looking for. This is an "I do" so what you're going to hear is words coming out of my mouth but you're also going to hear what I am thinking. Ok, they're lots of different colours in here so I can see a brown and some red and I'm sure I've seen that before. It comes from a plant. Ok, but there's not just one shape of a leaf, there's all different types of leaves here and some of them are bright green and some of them are different colours and this one looks half dead to me. As well as seeing leaves off plants, I can see some whole plants so I can see the leaves and I can see the stem. I can also see the roots that are coming out and this plant has really long roots so that must be an entire plant but what I'm seeing on other things is little parts of a plant. So plants can all be different heights and different sizes. Ok so that's an example of an "I do it". Ok, that's what I'm looking for.

In this introduction Stella explicitly taught the skill of observation as evidenced by thinking aloud to explain her own observations such as, "I can see the roots that are coming out and this plant has really long roots so it must be an entire plant". Think-aloud is a feature of the "I do it" phase of the GRR that Stella has used in this excerpt to provide students with insight into her own metacognitive thinking. It is important to note that she used the first person in her think-aloud to model the skill of observation. Stella explained the purpose of the think-aloud strategy to model the skill of observation in her reflective journal:

> Modelling expectations for students is essential and ensures students understand the task explicitly. Demonstration to observe different parts of plants in the mystery box was used to make observations of each specific item in the box, as well as "self-talk" to make links and connections between plant items in the box.

The "I do it" phase of instruction was followed by the "We do it" phase in which the students applied the skill of observation using what they had been taught in the “I do it” phase, with teacher guidance and support using questioning (Transaction 2) to make observations of items in a mystery box using a magnifying glass (Figure 4.3). The task required students to work in pairs within their science teams to make observations of the items, think about what they knew about the items and how they could be linked. Stella circulated between the science teams to scaffold students using the skill of observation as required. In the following transcript, which occurred in the “We do it” phase, Stella guides the students in one focus group to use the SIS of observation through careful questioning.

Figure 4.2 Mystery box activity

Transaction 2: Stella’s questioning in the “We do it” phase.

Stella	The magnifying glass can be very helpful at this point. You might like to use a magnifying glass to help you have a closer look.
Stella to Mia	What have you got?
Mia	A leaf.
Stella	Ok, how do you know that’s a leaf though? How can you make the connection that that’s a leaf because I would think a leaf is

something more like this? It's a leaf shape because it's something that's long and thin. Can you see any similarities between the two leaves?

Mia They both have like a long spine running through the middle.

Stella Ok, is that the only similarity you can see?

Mia Ah, they're brownish at the ends.

Stella Ok, so do you mean here? (pointing to a brown spot on the leaf)

Mia Yes.

Stella Ok, anything else you can see that's similar?

Mia They both have slightly …away spots on them.

Stella Ok, excellent.

Stella to all Ok, take one item out and I want to hear you talking. You don't have to look at your own item on your own. You could actually be looking at one thing together.

Stella talking to another group:

And what have you got? Put them down here on the table. Who else is in this group? Can you make any connections about these two things? Can you make any link? Are they similar?

Robyn They're both brown and they're both seeds.

Meg And they're small.

Stella How do you know they're both seeds?

Meg [inaudible]

Stella This one's got...they seem to be holes don't they? What do you think is in the holes or was in the holes?

Robyn Insects.

Stella Ok, and what about this one here. It seems to have one big hole. If you touch that, there seems to be three or four little shaped objects in there. What do you think they might be?

In this excerpt taken from the "We do it" phase of the GRR Stella is scaffolding students' observations by probing their responses with further questions to ensure they make scientific observations and links between the plants in the mystery box. During the "We do it" phase in each lesson questioning was used for multiple purposes; to scaffold students towards thinking more deeply about what they were observing; to check for understanding as well as to uncover errors and misconceptions. Stella's questioning in this excerpt prompted students to expand their observations by attending to details, demonstrating their use of the skill.

The teaching of the skill of observation in lesson one was planned and delivered in such a way to scaffold students' learning. Stella initially taught the skill explicitly in the "I do it" phase using two strategies, modelling and think-aloud. She provided students with a model to follow before they practised the skill of observation using a magnifying glass in the "We do it" phase of the GRR. Through revisiting the skill in the "We do it" phase using teacher to student probing questions and classroom discussion, Stella guided students to observe the plants as well as develop their conceptual understanding about the links between the plants. Stella made an entry in her journal reflecting on the purpose of the hands-on observation activity.

Reflection 1: Stella reflecting on collaborative group activity:

> Students worked in their ability grouped science teams to make observations (orally only) about items in the mystery box. Working as a team, students were able to make observations about individual items, as well as making connections of the items in the box. Students loved the opportunity to have a "hands-on" task to complete, and the use of magnifying glasses (explicit teaching of use occurred in Term 1) encouraged greater participation and more awareness of the intricacies of each item and their link to each other.

Stella also reflected on the benefits of scaffolding students' learning using the phases of the GRR.

Reflection 2: Stella reflects on the purpose of "I do it" phase of GRR:

> I actually love this strategy as it provides a solid base for students to follow the task. I feel that students don't require as much "thinking time" or "take up time" if they have first watched me undertake the task. Particularly low achieving students benefit from this method, as it provides them with more scaffolding and enables me to more efficiently "chunk" learning, for example, I might say, "Think about what was the first thing I did when I did the "I do it" or "How might you do that?" or "Show me".

4.3.3. Reflecting on students' understanding of SIS

The inquiry focus for the term-2 Life and Living unit was a bean seed investigation in which students were supported to plan and conduct an investigation of the conditions that affect plant growth. The six SIS taught in the Life and Living unit were all required for students to be able to successfully implement the bean seed investigation. In term one some of the SIS had been previously taught, however, many students still needed more explicit teaching and practise of the skills before they could use the skills to conduct an investigation as evidenced in Stella's reflective journal (Reflection 3).

Reflection 3: Reflecting of students' prior knowledge of SIS

> I find Term 1 investigations very difficult as we write the entire investigation together. Students come from different classes and have various levels of knowledge and different experiences. As the year progresses, and I have modelled with "I do it", I find it easier for the students as they have an exemplar in their books and know my expectations.

The ultimate goal of instruction is for students to apply the SIS independently; therefore, Stella considered how she would structure the learning sequence so that her students were well prepared to work in their science teams to carry out the bean seed investigation. But in order to make decisions about the order of teaching the skills and which phase of GRR to use Stella also considered students' prior knowledge and experiences using each skill as evidenced in Reflection 3.

In the following excerpt from her reflective journal Stella reveals her thinking around the phases of the GRR. This is significant because it reinforces her perception of the benefit of using the "I do it" phase followed by the "We do it" phase of the GRR to scaffold students' learning.

Reflection 4: Stella reflects on the phases of the GRR

> Sometimes I am uncertain about students' prior knowledge [if I haven't already pretested that specific area] and so wonder whether I need to spend the time using this strategy ["I do it"] or go straight to the "We do it". It is easier to start at the "I do it" and then move forward quickly to "We do it" rather than start at "We do it" assuming prior knowledge and understanding and then have to go back. With time constraints in our overcrowded curriculum, it does take longer to use this strategy, although I firmly believe the long-term effects outweigh the short term ones.

In lesson three (see Appendix 8 for Lesson Outline) the students set up a bean seed experiment (Figure 4.3). In this activity students were guided to set up one cup, each containing two bean seeds prior to working together in science teams to plan and conduct an investigation of the conditions that affect plant growth. Stella introduced the lesson with the "I do it" phase by establishing a purpose for learning and making it explicit as illustrated in Transaction 4. She used this strategy to introduce all of the lessons in the Life and Living unit thereby ensuring that her students were aware of the reasons for completing the activities. She communicated the purpose for learning with WALT (We Are Learning To…) on the lesson PowerPoint as well as through a teacher lead whole class discussion. One representative example where the purpose of the lesson is established in the "I do it" phase is shown below:

Transaction 4: Stella establishes a purpose for learning in the "I do it" phase.

01 Stella	I gave you a bit of insight this morning about what we were doing. Can anyone remind the group what one of our jobs is this afternoon? Henry.
02 Henry	We're going to plant bean seeds.

03	Stella	We are going to plant seeds. Does anyone know what type of seeds we're going to plant? Rachael?
04	Rachael	Bean seeds.
05	Stella	What do you think the purpose of planting those bean seeds is? Why would we be doing that as part of our Life and Living unit? Peter.
06	Peter	So we can see it sprout and you can see the whole life cycle of the bean plant.
07	Stella	So we can see it sprout. Tell me the second part.
08	Mary	So we can see the roots growing because it's a seed in a cup.
09	Stella	So we can see the roots growing. What are we really looking at this term in our science unit? We've already started a little bit. We're looking at life and living. Life, but what's the second word I'm looking for?
10	Mia	We're looking at a life cycle.
11	Stella	That's right, we're looking at a life cycle so hopefully over the next two weeks we'll start to see part of that life cycle and then you can take these bean seeds home and perhaps you can plant them in your garden at home and watch the entire life cycle.
12	Stella	Ok, today remember this term we are looking at BIG IDEA – How does time affect me? So we're starting to look at life cycles and timing of our life cycles. Today we're going to have a bit of a look at bean seeds and we might have a quick look at the packaging of them and I wonder why they are wrapped in the packaging they are in. We'll talk a little about that. We're also going to look at a procedural text, a procedure for getting our bean seeds up and running and germinating them. So we'll look at our procedure for that. You're going to work in teams to prepare your bean seed and then we'll talk about, and although we won't get it done today, but we'll start making observations and recordings of our bean

		seeds germinating in the coming weeks. At the end of our lesson today we'll have another look at our TWLH chart. Ok, so here's that chart now. Can anyone remember what we think we know? Mary.
13	Mary	Plants and animals life cycles.
14	Stella	Yes, we learnt about plants and animals life cycles. Chloe.
15	Michael	Bean seeds smell bad when they're cut open.
16	Stella	Yes, bean's seeds smell bad when they're cut open after they've been soaked. That was something a lot of people picked up on. Ella.
17	Sharon	The basic needs of plants and animals.
18	Stella	The basic needs of plants and animals. Are they the same or different?
19	Sharon	They're different.
20	Stella	They're slightly different aren't they? Peter.
21	Sharon	Some life cycles can be shorter than others.
22	Stella	Yes, very good thought……….Ok so they're things we learn. Has anyone got some idea how we came to that conclusion? Any idea how did we come to the conclusion of those things? (Pause, no answers so teacher rephrases) How did we learn about that? How did we learn about life cycles? Yes.
23	Tom	From discussion.
24	Stella	Yes, we talked about it as a class. How did we learn that the soaked bean seeds smell disgusting? Rob.
25	Rob	We smelt them.
26	Stella	Yes we could smell them. So we actually did a little investigation. We did an activity last week that we observed things and we were

able to smell that. Matty.

27 Matty We did a class vote.

28 Stella Yes, we did a bit of a class vote and survey one day as well didn't we?

In this transcript which occurred in the "I do it" phase, Stella explicitly introduced the purpose of learning by providing an explanation of what students will be doing in the lesson and also elaborating on why they were doing it (e.g., Transaction 4, Utterance 12). Stella also used questioning as a strategy to gauge students' understanding of the purpose of learning. One student, Peter, demonstrated his clear understanding of the purpose of learning when he answered Stella's questions with details about the life cycles of plants and animals. This shows how Stella used questioning as a strategy to formatively assess students' prior knowledge and understanding. The questioning continued to probe students about their understanding of science concepts with an emphasis on asking students to provide evidence of how they came to conclusions, for example, "How did we learn about that?" The one-on-one dialogues in Transcript 4 provide evidence of the teacher asking students to elaborate or to clarify their answers to promote engagement, while providing evidence of the extent of each student's learning so that the teacher is able to adjust instruction to better meet the learning needs of her students. In addition, Stella's questioning created dialogue around reasoning, a vital skill required in science, enabling students to suggest possible reasons for findings and observations. The interesting aspect of Stella's questioning is that she does not appear to be seeking a pre-determined right answer but is encouraging students to express their opinions.

Establishing a purpose for learning is an important part of the "I do it" phase that provides students with a clear goal for learning as well motivation for engaging in learning (Fisher & Frey, 2008; Hattie, 2012; William, 2011). In doing so, it is important that the teacher gauges students' prior knowledge and understanding in relation to the learning intent and makes adjustments that cater for the individual needs of students.

Later in lesson three Stella guided students step-by-step to set up their individual bean seed experiment in the “We do it” phase, gradually transferring responsibility to students while still providing necessary scaffolds for learning. In the following transaction, Stella guides students through the process of setting up their individual bean seed cup while also encouraging the use of scientific language.

Transaction 5: Stella encourages scientific language in the “We do it” phase.

Stella	Now what we want to do is we actually want to see our bean seeds grow. So what we’re going to do is we’re going to put them between the paper towel and the cup. We’re going to have two bean seeds each and we’re going to put one on this side and one all the way around on the other side. Why do you think we don’t want to put two seeds together? Peter.
Peter	They won’t form the roots because they’re too close together.
Stella	Ok, the roots might not form. Jack.
Jack	If you put them too close together they may grow together and make a big one.
Stella	Yes, they might get entwined and we may not actually be able to see which plant root is from which plant. So, what you will need to do and I’ll show you first, is you’ll need to get two seeds each. Now, the little black…, we called it a slit until we learned what it was called. Who can remember its name? Lots of people, Lana.
Lana	The hilum
Stella	Yes, the hilum. What’s going to happen at the hilum? What’s the hilum for? We saw that the other day?
Ellen	When the seed opens it comes out.
Stella	That’s right. So once the seed’s been soaked that hilum is where the first root’s going to come from isn’t it? So which direction do you think we need to plant our seed? John.

John	Facing up this way in the cup.
Stella	Facing up this way (teacher shows class).
John	Yes.
Stella	What's the first part of our seed that's going to grow? Is it the root or is it the stem?
Students	The root.
Stella	The root, so which way do you think we should plant it if we're going to help it out a little bit?
Ellen	Put it with its slit on the bottom.
Stella	On the bottom? Hands up if you think we should plant it on the bottom? (Some hands are raised). Any other ideas? Yes.
Edward	Having the hilum up on the top.
Stella	So that was our first choice, up the top or down the bottom? Does anyone think we should face it to the side? (No raised hands) Ok, I'm going to let you do what you think is right. Perhaps in your group you could have one person plant theirs so the hilum's up and another person plant theirs so the hilum's down and perhaps the third person cold plant theirs with the hilum to the side. So you're going to decide now. You've got ten seconds to decide. (Students discuss with their science teams and make decisions about the direction of seeds).

In this excerpt Stella provided scaffolding with a whole class explanation detailing where to place the bean seeds but she also used prompts and questions to guide students to make links with prior learning and apply their knowledge about the hilum to a new situation. They had previously experienced learning about a seed's hilum but in this situation Stella wanted them to apply what they had learnt about the seed's hilum to make decisions about the direction of seed placement in the bean seed investigation. She prompted students with hints to think about their prior learning and apply it to an unfamiliar situation. Fisher and Frey (2008, p. 43) explain the purpose of prompts in the “We do it” phase of the GRR, “Prompts can be phrased as statements or questions, but the teacher should not assume so much responsibility as to tell the student what information is missing. Instead, the prompt is designed to guide students’ thinking”. Also noteworthy in Transaction 5, was the extent that Stella’s prompts and questioning encouraged many students to contribute to express their opinions. The conversations are not dominated by a few students.

Figure 4.3 Bean seed experiment

4.3.4. Questioning, prompting and cueing to scaffold the SIS in lesson four

The skill of observing was an important prerequisite for students to be able to accurately make observations of their bean seed investigation. This skill had previously been explicitly taught in lesson one, however, structured teaching using the GRR required that the teacher regularly assesses students’ understanding and purposefully plan interrelated lessons that transfer responsibility from the teacher to the students (Fisher & Frey, 2008). Stella understood her students very well and planned lesson four to provide revision of two science inquiry skills that would assist students to successfully conduct their bean seed investigation. In the following excerpt from her reflective journal Stella reveals her thinking around the purpose of revising the skill of observation in lesson four.

Reflection 4: Stella reflects on the purpose of revising the skill of

observation in lesson four.

> Using our bean plants growing in a tissue, we identified what observable features could be observed in these plants. These ideas were written on the board – stem height, root growth, number of leaves and colour of stem and leaves. This activity was undertaken prior to students working in their science teams to make observations about their three cups containing bean plants as part of their team investigation.

Stella designed part of the lesson after noticing how students had been making observations of their bean plant that was growing in a tissue and realising she needed to give her students further direction with the Science Inquiry Skill, observation. In this teacher-led discussion that occurred in the "We do it" phase of lesson four, Stella uses questions, prompts as well as cues to scaffold students' developing understanding of the skill of observation.

Transaction 6: Stella revises the skills of observation in lesson 4.

01	Stella	So let's first of all talk about what is an observation because we've been making observations because every time you leave the classroom to go and get your lunch bag I see you going by these tidy trays that I've moved in the sun so you can observe your plant growing. So I don't want you looking at the board. Can you please tell me what you are observing about your plant? Rachael.
02	Rachael	It's dying and its roots are like rotting.
03	Stella	Right. So you're looking at more than just the seed. You're looking at the roots and you're looking at the bloomage at the top. Good. Yes Peter.
04	Peter	Make sure my plant doesn't dry out.
05	Stella	Ok, so you're monitoring how much water is in your cup. What do you think is a good amount?
05	Peter	10 millilitres.
06	Stella	10 millilitres. Are you measuring 10 ml each time you're pouring

in or taking a guess?

07	Peter	Yes
08	Stella	Ok, any other ideas about what you might be observing when you're observing your plant? Let's have a look at this beautiful big one here. It belongs to Christopher and amazingly enough this sister's plant is growing so much upstairs isn't it? So when I look at this plant I can see that bean seed we originally planted in the tissue. So….and it's got some changes to it. It looks different now to when I saw it when Christopher first planted it between the cup and the tissue. I can also see….what do we call this green part up here? Travis. Ok please put your hand up.
09	Travis	Stem.
10	Stella	Stem. Ok great and what are all these wonderful green things here at the top there? And that's what creates the photosynthesis we're looking for. What do you call those?
11	Ellen	The leaves.
12	Stella	The leaves, that's right. And here we have all those pale yellow lines that are down the bottom their circling around the bottom of the cup. Michael what do you call those? Michael.
13	Michael	Roots.
14	Stella	So, I can make observations. I can also take measurements as well of a plant. I'll talk with you when we'll be doing that today. Ok, so an observation is something learnt from watching. Are we watching when we look at our plant growing?
15	Students	Yes
16	Stella	Can we see our plant growing?
17	Students	No

18 Stella No. So it doesn't appear to be growing but from one week to another when we are recording our information in the journal we can certainly see that it's growing and we can measure. We can measure the object and we can see if there's a pattern forming there in the growth of our plant. Is there a pattern forming there do you think? It will be interesting today when you take the measurements. The second point there is that observations are a way to gather and record information.

19 Stella We are not only gathering and recording information on the bean plant growth but you are also doing an investigation with three cups in your science teams and we're gathering that information at the moment. What one of the groups has been telling me is that their cup keeps getting knocked over under the stairs. So although they're not recording and measuring the height of that plant at the moment they are certainly making observations about that plant being knocked over and they can start recording that, ok. How do we make observations? It's about using all of our senses to observe and gather information accurately. When I was talking to the class upstairs yesterday and we were talking about how important it is to be precise with your measurements and when you're making your observations that you need to record your observations….

20 Students Accurately

21 Stella So when you're going around measuring your bean plant growth at the end of your investigation, just because Eliza says it's 35cm high doesn't mean you should accept that. You each need to check that measurement, Ok, because it is important that we get accurate measurements because when you're writing up your investigation if you're not using accurate measurements of course…?

22 Tyler It could be wrong.

23 Stella It could be wrong. In the end your investigation might show the

wrong results.

[The discussion continued for a couple of minutes and concluded with Stella directing students' attention to the Observation poster on the window].

24 Stella Ok, so they're all ways that we can record our observations and those ways are straight off the poster. Can you see straight behind Christopher's head, 'Ways to record Observations.' So, if you need to go back and look at those you can say to me, 'Mrs Keast can I please take a photo of my plant?' Ok, and that's fine because we want to cover as many ways to record our observations as we can.

In this excerpt, Stella used three strategies to revise the skill of observation; questioning, prompting and cueing. She questioned students to draw out scientific names for parts of a plant (e.g., Transaction 6, Utterances 10, 12 and 14). She used prompting to explore the reasons for making observations and to help students understand the importance of making accurate scientific observations (Transaction 6, Utterance 19 and 21). Stella also used visual cues to scaffold students' developing use of scientific observation. Fisher and Frey (2008) explain the essential role of cues within the framework of the GRR; "Rather than simply tell students the answer or how to apply the learning, the teacher uses cues to make sure students are taking on responsibility to do the work" (Fisher & Frey, 2008, p. 47). Cues provide a higher level of support than prompts or questions. Examples of cues include graphic organisers and posters. Stella had posters of each Science Inquiry Skill on the windows of her classroom that were commonly used as cues to scaffold students' learning (Appendix Three). In this excerpt Stella directed students to refer to the observation poster if they needed some ideas about ways to record their observations. The revision of the skill of observation enabled students to work in their science teams in the "You do it together" phase to make observations of their three bean plants, which followed the "We do it" phase as evidenced in the following excerpt from Stella's reflective journal (Reflection 5) below.

Reflection 5: Stella reflects on students' use of observation in lesson 4.

> We identified what observable features could be observed in plants. These ideas were written on the board - stem height, root growth, number of leaves and colour of stem and leaves. This activity was undertaken demonstrating prior to students working in their science teams to make observations about their 3 cups containing bean plants as part of their term investigation

Students worked in their science team to make observations and identify similarities and differences between their bean plants (Figure 4.4) in their investigation. They used observable features used in the "We do it" phase of this activity listed on the board.

Figure 4.4 Bean plants

4.3.5. Questioning, explicit explanations and cueing to scaffold the SIS of fair testing in the "We do it" phase of lesson four

The skill of fair testing was also an important prerequisite for students to be able to conduct their bean plant investigation therefore Stella carefully guided students using the phases of the GRR to toward developing the Science Inquiry

Skills necessary for conducting their investigation. Following revision of the skill of observation in lesson four, Stella planned a second “We do it” phase in which she focused on scaffolding students’ understanding of fair testing. Again, she used questioning as a strategy in the “We do it” phase to promote rich teacher-to-student dialogue to engage students in reflecting on their own bean seed investigation, however, this was combined with detailed explanations about potential problems that could impact on whether a test is fair or not (Transaction 7). Stella uses a PowerPoint slide: Investigation in Science: Cows Moo Softly and also makes reference to the fair test poster as a cue in the following excerpt.

Transaction 7: Stella revises the skill of fair testing in the “We do it” phase of lesson 4

01 Stella — Why have I put this slide up? What is so important as we’re getting to that stage in the investigation where we’re starting to write our investigation? Why is this slide so important? (points to slide that says “Cows Moo Softly”)

02 Sally — It says Cows, Moo, Softly and Cows means what are we going to change in our investigation and Moo means what do we measure in our investigation and Softly means what do we keep the same in our investigation.

03 Stella — Excellent. What would you like to say Eliza?

04 Eliza — Um, it’s like the rule for a fair test.

05 Stella — It is. It’s exactly right. It’s our rules for our fair test and when William [student in Tasmania science team] came to me this morning and said my plant’s been knocked over again and you were talking about something not being right what were you thinking of Will?

06 William — Ah, the measurements and two things had changed.

07 Stella — Two have changed and you think your measurement’s going to be affected. Ok, but the goal is right through the investigation

that we have to keep everything else the same. So we've had a bit of a problem with that particular group [Tasmania science team] because they've lost some soil and their plant's not...if it was going to be the same then somebody shouldn't have kicked all these plants over which of course we wouldn't do. So when we're investigating in science...and one of the reasons I wanted to bring this to your attention is you just can't put your plant, your seeds in the cup and forget about them. Ok, you need to look after them. So if you're giving the plant in the cup that we're putting out on the patio, out on the porch, out there…if you're giving it thirty millilitres of water each day what should you be doing with your other two cups?

08 Ellen Yes, giving it thirty millilitres of water each day.

09 Stella Ok, good. So the plants that are in my fridge have you been watering those? Ok you need to make sure you're still watering those cups. The cups in the cupboard; Hands up if you've been watering the cups in the cupboard, (one hand went up) the same amount as the cups outside?

10 Lana Yes.

11 Stella Excellent. Ok, one of the problems that we found in previous years is if you water them the same amount and the cups that aren't out getting nice and warm out in the sun and aren't having that chance to evaporate then those bean seeds can rot. Once we had some of the seeds rotting in the tissue. So what you might like to do rather than saying you're going to measure the same amount of water into the cup each day you could say that you're going to test that the soil has the same moisture level in it. It's the same wetness. You might like to think about that so when we get onto our experiment and …we're looking at our cups today, I'll come and talk to your group about that. Ok, but just keep in mind we only want to change one thing. Everything else has to stay the same. So change one thing, measuring

		something. Are we going to be doing any measurements today for our investigation with three cups?
12	Students	No.
13	Stella	No we're not. Ok, we're only going to be measuring them at the end of the investigation. But we are going to do today is we want to check and make sure we're doing a fair test because I think for a few people, for a few science teams, we're not following up on that enough. So we'll check with that today and of course this is the one that's most important. Let's make sure we keep everything else the same. Where have we seen that writing? Does anyone recognise that writing?
14	Sally	In a test.
15	Stella	Yes we did it in a test the other day.
16	Polly	Up here (Student points to poster on window).
17	Stella	Yes that's right. I've taken little screen shots. Ok, so if we go back there's that gorgeous little cow. Ok, that's the same as up on the poster. Ok, so any time you need to refer to this information you need to go back to those posters.

In this excerpt Stella made reference to the PowerPoint slide of Cows, Moo, Softly and (Transaction 7, Utterance 01) and questioned students to draw out their understanding of fair testing. One student responded with a clear definition for the process of fair testing as evidenced in Utterance 02. Next, Stella explicitly explained her thinking to clarify for students the process of fair testing and also demonstrated how to tackle the decisions necessary to successfully complete a fair test as evidenced by her reference to the problems experienced by Will (Transaction 7, Utterance 06) and also explaining one of the problems that was found in previous years (Transaction 7, Utterance 11). Stella used the PowerPoint slides as well as the fair test poster on the classroom window as cues during this excerpt (Transaction 7, Utterance 17). When teaching and revising the Science Inquiry Skills and during investigations, Stella often directed her students' attention to the SIS posters on the window as cues of all the thinking about the Science Inquiry Skills that was represented on the posters.

4.3.6. Questioning students while they practise the skill of fair testing in the "You do it together" phase of lesson 4

In the following excerpt from the "You do it together" phase of lesson five, Stella identified students' knowledge and understanding of science inquiry skills and concepts through teacher-student interactions and then scaffolded their understanding of fair testing procedures and the basic needs of plants.

Transaction 8: Stella identifies and scaffolds students' knowledge and understanding of fair testing procedures in the "You do it together" phase of lesson 5.

Science group with Ellen, William, Lana, Edward

01	Stella	So what do you think?
02	Ellen	These roots have grown a bit horizontal.
03	Stella	So this one was in the fridge. This one was…….?
04	Edward	Under the stairs.
05	Stella	Under the stairs. So what were you trying to……..you might break that so just be gentle. What group were you in? Were you in the temperature group, the soil group?
06	Lana	The temperature.
07	Stella	The temperature group. Ok, so this one was outside in the sun. That one was……..?
08	Lana	In the cupboard.
09	Stella	In the cupboard, ok, and that one was in the fridge. Ok, do you remember, I think it was last week, we talked about only having one thing that we're changing? What are you changing?

10 Lana The place of where you put the bean seed.

11 Stella The places where we put them but the choices were we were going to change the amount of sunlight they got or we were going to change?

12 Lana The temperature.

13 Stella The temperature. What have you changed?

14 Lana The temperature.

15 Stella Have you only changed the temperature?

16 Lana And the sunlight.

17 Stella And the sunlight as well.

18 William Oh no not really.

19 Ellen Cause we put all these so they didn't get any sunlight. We put that one under the stairs where it couldn't get a lot of sunlight and the cupboard where it couldn't get sunlight and the fridge.

20 Stella I know that you put that in the fridge but you probably, you have actually changed two variables. So you don't change two things. That's ok cause we're going to go on with the investigation but you do need to be aware when you're writing up your results and your procedure that perhaps you had made two changes. Do you know what this is called when you see a plant that grows a really looooong stem? What's it looking for? Why do you think it's grown such a long stem? What's it looking for?

21 William It's looking for sunlight.

22 Stella It's looking for the sunlight, that's right. And so what some plants can do, and you see this inside your house some times. If you have a plant just inside the window the leaves of that plant will continuously grow towards the window because it's looking for?

23 Students Sunlight.

24 Stella Sunlight, it's called phototropism. Can I write it on your book and we'll rub it out later? Photo, do you know what the word photo means?

25 Ellen Yea.

26 Stella What does it mean?

27 William Picture.

28 Stella To take a picture, but it's all about light isn't it? Phototropism (T writes in book) and it actually means a plant, it reaches or it searches for sunlight. So when I first saw your plant today that was what made me wonder if we had one variable or two because this plant's been looking for sunlight. Alright, so what are you going to do now? What's the next step?

29 William Ah, we haven't done our procedure.

30 Stella Are you doing it as a 'You do it together?'

31 William Ah well we're doing it alone cause I'm doing the one under the stairs and she's doing the fridge and she's doing the cupboard so we can't really do the same procedure.

32 Stella If someone was going to come back and read your procedure though, are they actually able to repeat the whole experiment? So you have to do each one. What you can do is you can say, "Repeat steps two to four. You need to make sure if someone read your work William, they could repeat the entire investigation, not just your part. Alright?

33 William Yea.

34 Stella So it's a good idea to do as a 'You do it together' ok to make sure you're following the way I taught you how to do a procedure but at the end of the day, um, the 'You do it alone' only needs to be the discussion and conclusion at the very end. Ok, the rest I still want you to do it as a 'You do it together'.

35 William So do we finish this first?

36 Stella Ah, yes you can finish this and you can work on your diagrams today. Have you had enough discussion as a group about the growth of your plants? I'm wondering if that one's…they're looking a little dry to me. Have you been watering them?

37 William That one's not that dry.

38 Stella You don't think that one's too dry? Maybe give them all a bit of water today, ok.

39 William But why isn't that one reaching for sunlight as much?

40 Stella Which one?

41 William This one.

42 Stella So, some people grow taller than other people. Ok, we're all individuals. Um, perhaps that one was facing closer to the window and the other one started to grow that way. When you put it back in the cupboard you could turn it around a little bit. You might find by next week that on this side…is that A, plant A?

43 Ellen Yes.

44 Stella It might have grown towards the window a bit. Interesting, the colour difference as well. Did you comment, did you observe the colour difference?

45 Lana Yes. It might not have been getting a lot of sun to make it like really green.

46 Stella Mm, and in fact, um, do you remember the word I used? That plants, they make their own energy from sunlight and from water. Do you remember what that was called?

47 Ellen Photosynthesis.

48 Stella Photosynthesis, very good, and so plants actually, they use something called chlorophyll, which makes them look green, to

photosynthesise. If the plants are in the cupboard are they able to photosynthesise?

49 Students No.

50 Stella So do you think those poor plants would use all their energy that they've got from the cotyledon in the seed to turn green because they don't have any sunlight so it's pointless turning green. So they're just going to use all their energy to hopefully find some sunlight. So perhaps we haven't been great carers. We haven't looked after that plant very well.

This example is typical of the conversations between the teacher and students in the "You do it together" phase. Transaction 8 shows the important role of teacher-student dialogue in formatively assessing students' learning status and scaffolding their developing Science Inquiry Skills. Stella carefully posed questions to determine students' understanding of fair testing processes (Utterances 9, 11, 13, 15) and also uncovered errors and misconceptions (Utterances 11, 20, 28, 29, 30, 31, 32). Rather than simply telling students about various science concepts such as photosynthesis and phototropism, she strategically asked questions to guide their thinking about such concepts (Utterances 42, 44, 46) and provided explanations on a needs basis (Utterances 26, 48). By prompting students, asking questions about their observations, and then providing teaching at just the right moment, Stella guided her students to make connections between their observations and scientific explanations.

4.3.7. Summary

In all the lessons, Stella demonstrated application of the fundamental theory that guides the GRR expressed by Fisher and Frey (2008) in planning and teaching the Life and Living science unit. Stella knew her students and content well and thus purposefully structured the teaching to facilitate regular formative assessment of students' understanding of the content and SIS. This informed the purposeful planning of interrelated lessons that transferred responsibility from the teacher to the students.

Analysis of lesson transcripts and the teachers' reflective journal reveal key strategies used within each phase of the GRR for scaffolding students' learning to gradually release the responsibility from teacher-as-model to teacher-as-guide to students learning together with their peers.

The "I do it" phase of instruction was marked by two key strategies; establishing a clear learning purpose for each lesson and teacher modelling of Science Inquiry Skills with think-aloud. At the outset of every lesson Stella explicitly established a clear purpose for learning to ensure that her students understood not only what they will be learning but also why they will be doing particular tasks and activities in the lesson. Generally speaking, one or two Science Inquiry Skills that supported the learning intent were the focus for explicit teaching in each lesson. Having established a clear learning purpose, Stella ensured that the students had a model from which to learn so she demonstrated each skill whilst thinking-aloud as a strategy to provide students with insight into her own thinking. Four strategies used in the "We do it" phase that emerged from data analysis were explicit explanations, questioning, prompting and cueing. Stella used questioning for a variety of purposes. She commonly asked questions of students prompting them to elaborate or to clarify their answers. Answering her questions was a valuable activity because it prompted students to think about what they were learning and make vital connections. When necessary, Stella prompted students to think about prior learning by rephrasing questions and statements. Questioning also provided Stella with valuable feedback about students' understanding of SIS and enabled her to determine how to respond and how best to scaffold students' development of the skills. In addition, Stella asked questions to uncover misconceptions and commonly responded with explicit explanations to get students back on track or extend their understanding about science concepts and skills. Cues on PowerPoint slides and SIS posters were a routine part of the "We do it" phase. They provided important visual information for teaching new skills and if a student or group had difficulty recalling prior learning, Stella directed them back to these cues to remind them of all the thinking about the Science Inquiry Skills. Graphic organisers were also used in some lessons as cues to guide students' thinking, for example, in lesson one students were provided with a framework to guide their thinking as they discussed observations of plant growth with peers.

The learning and application of SIS that occurred in the "You do it together" phase was facilitated by student-student and teacher-student interactions. Students supported each other's thinking through discussions and the important role of teacher-student dialogue in formatively assessing students' learning status and scaffolding their developing Science Inquiry Skills was also revealed. However, the design of lessons using "I do it" and "We do it" phases to explicitly teach Science Inquiry Skills prior to the "You do it together" phase enabled Stella to scaffold students' understanding of SIS so they could work together in science teams to conduct their bean seed investigation using the SIS in the "You do it together" phase. This afforded Stella with the opportunities to direct her attention to the groups of students with greatest need. While science teams engaged in collaborative inquiry, each student recorded his or her thinking in a science journal and refined thinking about new concepts and skills, providing individual accountability. Essentially, the "You do it alone" phase was embedded within the "You do it together" phase.

In summary, the teacher taught the Science Inquiry Skills relevant for the context of the science unit using strategies within the phases of the GRR and identified students' knowledge and understanding (formative assessment) of science inquiry skills and concepts through teacher-student interactions. The strategies used within each phase of the GRR are illustrated in Figure 4.5 below.

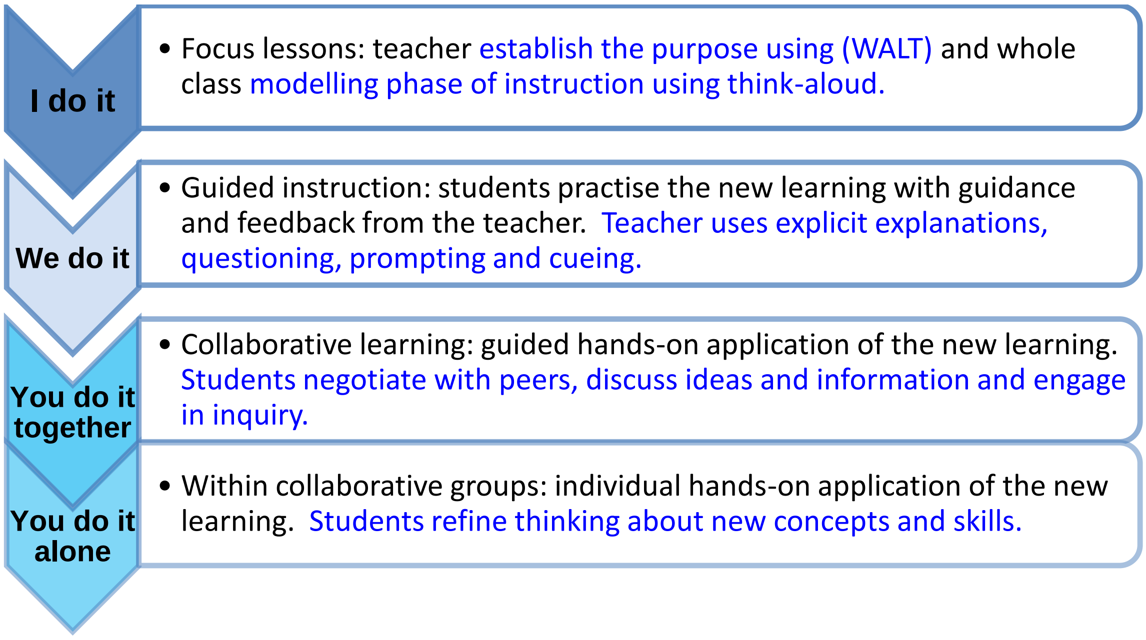


Figure 4.5 Strategies within the phases of GRR

4.4 ASSERTION 2

The teacher demonstrated flexibility in time and order of the GRR phases, which was influenced by teacher-student interactions for monitoring students' learning status.

An analysis of data from the classroom observations, informal interviews and the teacher's reflective journal entries suggested that in the classroom setting, the order of the instructional phases, I do it, We do it, You do it, was influenced by the context relevant to the science unit combined with the teacher's ongoing formative assessment of students' learning. Stella purposefully planned interrelated learning experiences that transferred responsibility from the teacher to the students. In doing so, she prepared her students to understand and apply Science Inquiry Skills necessary for the activities and investigations in each lesson. In most lessons one Science Inquiry Skill was explicitly taught while other skills were revised when necessary. Stella identified measurement as a focus for explicit teaching in lesson six so that students were prepared to work together in science teams to make accurate measurements of their bean plants.

4.4.1. Flexible lesson structure

Stella's flexible approach implementing the GRR afforded her opportunities to formatively assess students' ability to demonstrate SIS and determine the structure of the lessons accordingly, for example, in lesson six she realised that she had not provided enough guidance and scaffolding in the "I do it" phase to enable students to create a table to record their data. Consequently, she stopped and reviewed the skill before further releasing responsibility to the students. In accepting the proposition that new knowledge grows out of experience then it is important for students to experience the phenomenon of measuring and recording data before understanding it. Seeing the teacher (I do it) may help to focus attention on the task.

A breakdown of the structure of lesson six provides an example of how Stella flexibly used the GRR phases to teach the SIS of measurement (Table 4.1).

Table 4.1

Structure for lesson six

LESSON 6 SIS FOCUS Measuring and Recording Data				
GRR Phase	Time I do it (mins)	Time We do it (mins)	Time You do it together (mins)	Lesson 6 learning sequence
I do it	1			Clearly states the purpose of lesson and identifies this as WALT.
We do it combined with You do it together		5	2	THINK, PAIR, SHARE: Students use think, pair, share strategy to discuss their opinion about the statement, “Measuring accurately makes out data more reliable”.
We do it with I do it think aloud	1	3		Explicit teaching of ‘Measuring’ SIS. Teacher models how to use a tape measure then guides students practising the skill in science teams.
I do it	5			Teacher models how to label plants for investigation and clearly states the purpose of lesson section.
We do it		11		Teacher guides students as teams collect equipment and set up to label first plant as demonstrated in ‘I do’.
You do it together			7	Teacher monitors groups as they remove plants from cups and label.
I do it	4			Teacher clearly states purpose and models how to measure plants accurately and to record results.
We do it		2		Teacher guides students to practise recording measurement data in a table.
You do it together Stopped and retaught how to DRAW a table		6	1	Students work in science teams to draw a table to record bean seed investigation results. Students did not DRAW the table properly so teacher stopped the You do it and reverted to We do it.
Total time for each phase	11	27	10	

The predominant pattern that emerged in analysis of lesson six revealed the recursive nature of the GRR where the phases were repeated more than once in the lesson sequence. Figure 4.6 illustrates how the GRR phases were used flexibly in lesson six, moving between “I do it”, “We do it” and “You do it together” phases. Stella’s recursive use of the GRR phases provided a framework for the delivery of content which involved monitoring and scaffolding learning within each phase so that students were prepared to work together in science teams to apply the SIS they had learnt.

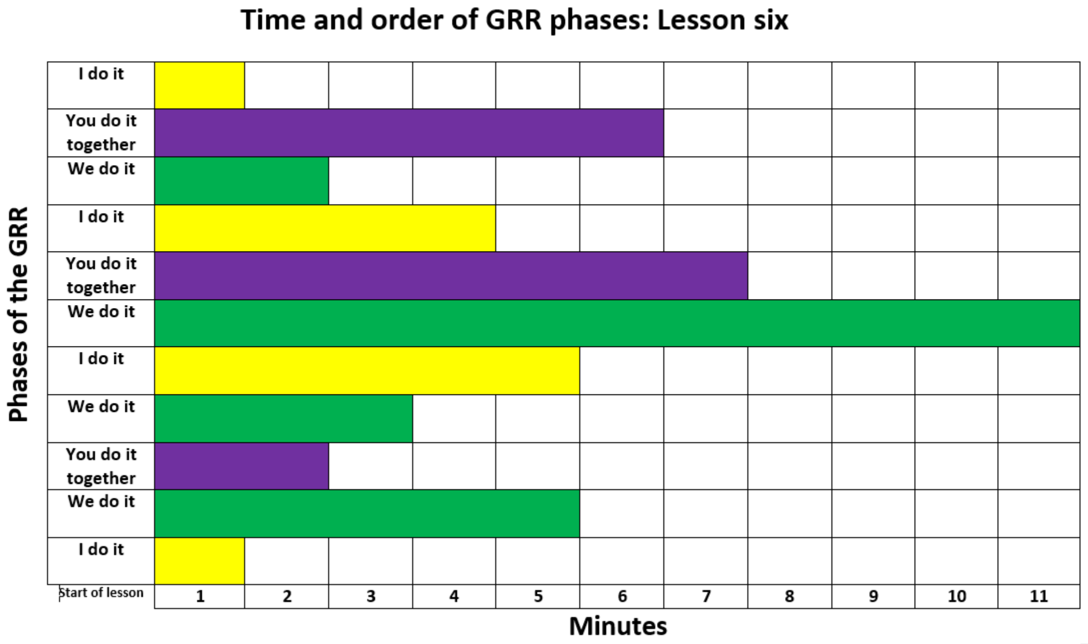


Figure 4.6 Lesson 6 GRR phases

During the sequence of eight lessons all but one lesson began with the “I do it” phase, which included setting a clear learning purpose for the lesson. Lesson seven was an exception, which began with the “We do it”, in which the purpose of the lesson was embedded. This was followed by the “You do it together” phase and concluded with the “We do it” phase which emphasised the importance of scaffolding and social learning. The “You do it” provides students with the opportunity for personal reconstruction or application of the ideas. In lesson seven students worked together in science teams, using many of the Science Inquiry Skills they had learnt to make observations of their bean plants, measure and record their results in a table, photograph and complete a timeline of their plants' growth. Evidence of the structure of all eight lessons can be found in Appendix 9.

A graph of the time spent on each phase in the eight lessons illustrates the time spent on the "I do it" phase was relatively short compared to the "We do it" and "You do it together" phases (Figure 4.7). Most lessons were one hour long. Lesson seven was an exception being two hours duration, which explains the extra time devoted to the "You do it together" phase. During the 45 minute "You do it together" phase of lesson seven students made observations of their bean plants in science teams and recorded these individually in science journals. They measured and recorded their results in a table. Stella also took photos of each science team's plants.

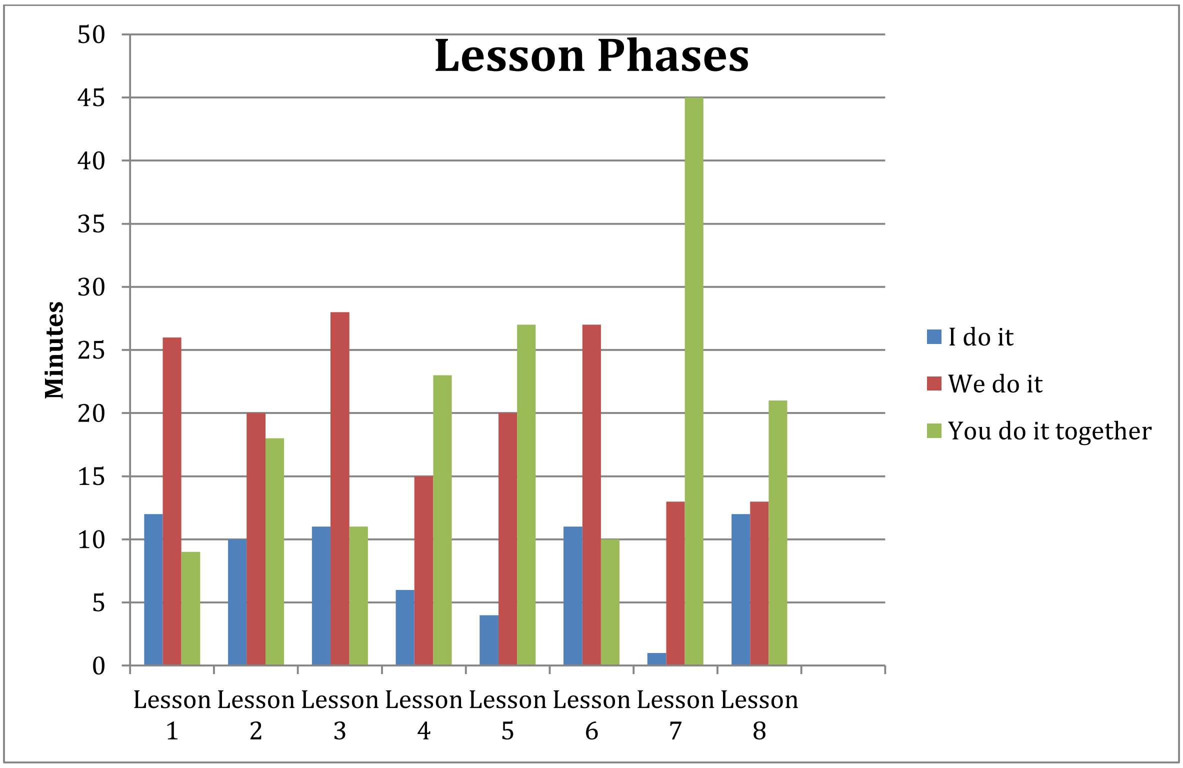


Figure 4.7 Time spent on GRR Lesson Phases

4.4.2. Teacher-student interactions for monitoring student progress

Stella was insightful in planning and implementing the learning sequence. She considered students' prior knowledge about the skill of measuring as evidenced in excerpts from her reflective journal.

Reflection 6: Stella reflects on lesson six:

I do it

Date 10 June 2014

Setting expectations for measuring accurately is an important part of this phase. I feel confident that with my "I do it" expectations set and modelled, students can complete a measurement in the "We do it" phase and record accurately their measurements. To ensure I was able to complete this phase of the GRR I had to use additional time not normally allocated to science to explicitly teach the skills of measurement.

We do it

Date 10 June 2014

This phase allows me to gain some knowledge of groups' abilities to complete tasks as during the "We do it" phase, I can determine from answers and conversations in groups, who I need to follow up with and further review of measuring activities. This phase allows a review of prior knowledge and allows the teacher to feel more confident before allowing students to "go it alone". Not all students can demonstrate their skills in a group – it tends to be only one or two confident students who take opportunity. Ideally, I would have chosen a less capable student from each group to demonstrate the "We do it".

You do it together

Date 10 June 2014

If students are provided adequate scaffolding and guidance in the earlier phases, they should be able to confidently work as a group to complete measuring activities. What I did discover was that I did not provide enough guidance and scaffolding in the "I do it" phase on how to create the table, and so we had to stop and review this later to ensure all students drew the table accurately in their science journal. Ensuring all students have the opportunity to take accurate measurements is important. A system needs to be in place that all students take turns otherwise more confident students may take over this phase without the direct supervision of the teacher. Students were able to demonstrate their knowledge and understanding of

> inquiry skill – measurement. It is essential that students understand the importance of this skill to ensure reliable data.

Reflection 6 provides evidence that Stella's instruction was marked by her desire to facilitate the learning of each and every student in her class. Her entries, reflecting on the GRR phases in lesson six, are indicative of many of Stella's lesson reflections, revealing a deep passion and commitment for providing appropriate learning experiences and support for all of her students to progress towards achieving competence in using Science Inquiry Skills. For example, Stella comments on how she scaffolds students using the phases of the GRR to teach the skill of measurement, "Ensuring all students have the opportunity to take accurate measurements is important. If students are provided adequate scaffolding and guidance in the earlier phases, they should be able to confidently work as a group to complete measuring activities". Additionally, the purpose of teacher-student interactions in the "We do it" phase for informing future learning experiences is revealed in the following journal entry, "This phase allows me to gain some knowledge of groups' abilities to complete tasks as during the "We do it" phase, I can determine from answers and conversations in groups, who I need to follow up with and further review of measuring activities". Stella's statement is significant because it shows the important role she places on teacher-student dialogue for formatively assessing students' learning status and scaffolding their developing Science Inquiry Skills. This is just one example of many in lesson transcripts and Stella's reflective journal supporting the assertion that her flexible use of the GRR phases was influenced by teacher-student interaction for monitoring students' learning status.

Further evidence of Stella's use of teacher-student interaction for monitoring students' progress was drawn from an informal interview. When asked, "How did you monitor students' learning within the phases of the GRR?" she responded as follows:

Informal Interview 1: Stella's monitoring students' learning in the phases of GRR

> During the filming of the lessons the formative assessment that I gathered was I would check with students so I would join in and participate in their

group discussion and listen in to what they were talking about and I could ask questions during that and so that was the “You do together” phase. In the “We do it” I got a good idea through questioning as we were doing an activity together. Usually what I found is that students put up their hands when they know the answer so by selecting students who don’t put up their hands I can gather some evidence as well of how those students who understand the concept. During the “I do it”, I guess there really isn’t any formative assessment as far as their science learning. I get a good idea of who can listen during that stage and the “You do it alone” we didn’t tend to do that a lot during our unit in year-4.

4.4.3. Summary

Stella’s lesson structure using the phases of the GRR can be described as being flexible and recursive, with every lesson following a different sequence. The sequence of the GRR phases, “I do it”, “We do it” and “You do it together”, was influenced by formative assessment of students’ knowledge and understanding of Science Inquiry Skills identified through teacher-student interactions in the “We do it” and “You do it together” phases. While Stella identified the “I do it” phase as being important for providing a model and setting expectations for each Science Inquiry Skill, the time spent on this phase was relatively short compared to the “We do it” and “You do it together” phases. These two phases were predominant, which afforded Stella many opportunities to monitor students’ learning through teacher-student interactions and provide extra support for students who needed it.

In summary, a relatively small amount of time was spent in direct transmission of ideas (67 mins in “I do it”) compared with the amount of transactional time (160 mins teacher questioning / students responding in “We do it”) and student interactive time (163 mins students working in small groups in “You do it together”) as illustrated in Figure 4.7.

4.5 Teacher’s affordances and constraints using GRR strategies

Research question two was, “What affordances/constraints does the teacher identify in using GRR strategies?" The term "affordance" describes the relationship between the attributes of an object or environment and the characteristics of the user (Gibson, 1977). It provides a direct approach to perceiving the value and meaning of objects or environments that afford users to perform particular actions. Certain objects or environments *afford* opportunities for action, however perception informs the individual of affordances. Gibson's (1977) definition refers to the utility that a system provides a user. Therefore, in applying Gibson's perspective to this study, the term affordances refers to the possibilities or advantages of the GRR and environment that enabled the teacher to implement a program for teaching Science Inquiry Skills in a year-4 classroom.

The teacher was encouraged to keep a reflective journal or diary to record thoughts and reflections about her teaching experiences and student learning outcomes. The teacher's reflective journal was a key data source, providing rich data in support of research question two. An analysis of the teacher's reflective journal sought to understand what opportunities were afforded and what constraints were identified in using the GRR as an instructional approach for teaching Science Inquiry Skills in a year-4 science class.

4.5.1. Affordances

To determine the affordances, the teacher's reflective journal was coded which identified first level categories according to the framework of affordances generated by qualitative data analysis as summarised in Appendix 10. The first level categories of affordances included:

1. The phases of the GRR provided opportunities for the teacher to explicitly teach SIS and scaffold students in the "I do it" and "We do it" phases.
2. The teacher's formative assessment in the "I do it" and "We do it" phases enabled the teacher to determine students' understanding for further follow-up in all phases.
3. The teacher's scaffolding in the "I do it" and "We do it" phases enabled students to use SIS in the "You do it together" phase in science teams

that were differentiated based on ability.

The second level categories and their implications for student outcomes that emerged from the current data were:

1. Expectations were communicated (students had an understanding of expectations).
2. Scientific vocabulary was promoted and practised (students developed an understanding of scientific vocabulary).
3. Science Inquiry Skills were scaffolded (students were able to practise SIS with scaffolding).
4. Cues were used to reinforce important aspects of each skill (students referred to cues as reminders of the key information relating to each SIS).
5. Science teams were ability grouped (students worked at their own rate in science teams).
6. Teacher worked with students and science teams who required more scaffolding (students demonstrated SIS with scaffolding).
7. Teacher monitored students' learning (students were monitored to identify mistakes, misconceptions and participation)
8. Students demonstrated their knowledge and understanding of SIS when working together in science teams.
9. Students worked at their own pace in differentiated science teams.
10. Science teams provided a supportive and collaborative learning environment for students to engage in student-student dialogue.
11. Students used scientific vocabulary modelled in previous stages.

Appendix 10 illustrates an elaboration of the first and second level categories and statements from the teacher's reflective journal that provide evidence of the affordance categories.

4.5.2. Constraints

In this study, the term constraint meant something that blocked something from happening or limited the event. Therefore, an analysis of the teacher's reflective journal sought to reveal evidence of challenges that were perceived by the teacher to inhibit or block her using the GRR as an instructional approach for teaching Science Inquiry Skills in a year-4 science class. Four categories of constraints emerged from data analysis. They were student accountability, time, differentiation and teacher talk. An elaboration of the four categories and statements from the teacher's reflective journal that provide evidence of the constraint categories are summarised in Appendix 11.

The four categories of constraints emerged from data analysis: (1) student accountability (monitoring students during collaborative learning ensuring individual accountability and equal participation in groups), (2) time (time to conference with individual students and additional time to cover "I do it", "We do it", and "You do it" phases), (3) differentiation (students move through the GRR phases at different rates, lower achieving students would benefit from the 'I do' stage being taught at a lower level or repeated), and (4) teacher talk (finding the right balance of providing adequate information in a timely manner). It was found, however, that the case study teacher adjusted her teaching to overcome many of these constraints. The four constraints are discussed (Chapter 6) in relation to the current study highlighting the strategies used by the teacher that aligned with the GRR model of instruction for overcoming these constraints.

4.5.3. Summary

In addressing research Question 2, an analysis of the teacher's reflective journal sought to understand what opportunities were afforded and what constraints were identified in using the GRR as an instructional approach for teaching Science Inquiry Skills in a year-4 science class. It was established that the GRR phases provided a pedagogical framework enabling the teacher to explicitly teach and scaffold students' learning SIS within differentiated science teams, gradually releasing the responsibility from teacher to students. In each phase of the GRR, students were provided with opportunities to practise SIS and demonstrate their understanding and application of skills which was largely influenced by the teacher's formative assessment through teacher-student discourse. However, the constraints or challenges that were perceived by the teacher to inhibit or block her using the GRR as an instructional approach for teaching Science Inquiry Skills included student accountability, time, differentiation and teacher talk. Nevertheless, the results of this study found that by reflecting upon her pedagogy and making appropriate adjustments, the case study teacher was able to overcome many of these constraints.

Chapter 5 **Student Learning Outcomes**

5.1.1. Introduction

Research question three, “What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model?” addressed the strategies used by Stella in each phase of the GRR to teach Science Inquiry Skills to students in a y-4 science class. In doing so, she modelled, guided, prompted and questioned her students whilst scaffolding their learning and gradually releasing the responsibility from teacher to students. In each phase of the GRR, students were provided with opportunities to practise SIS and demonstrate their understanding and application of skills. Throughout each phase of the GRR Stella gathered formative assessment data to inform instruction by being actively engaged in dialogue with students as a whole class and in small groups. All of this together enabled students to demonstrate oral and written learning outcomes to answer research question three. Notably, analysis of the quality of students’ written and oral learning outcomes in this study using the SIS Modified SOLO-taxonomy Rubric offers a way of revealing evidence of students in the “Queensland” science team discussing and questioning their ideas, applying fair testing procedures, making observations and accurate measurements, analysing data and offering scientific justifications whilst engaging in Science Inquiry.

This section addresses the outcomes achieved by students by examining data sources from one focus science team called “Queensland”, including students’ science journals, reflective journals, Pat Science Results and lesson transactions of discussions in the “You do it together” phase as well as the teacher’s reflective journal.

An elaboration of Science Inquiry Skills that were the focus of explicit teaching episodes using the GRR, previously described in Section 3.3.3, provided a framework for analysing evidence of the students’ learning in combination with a modified SOLO-taxonomy (Table 3.6). To this end a rubric was developed to identify the quality of students’ application of Science Inquiry Skills (Table 3.7).

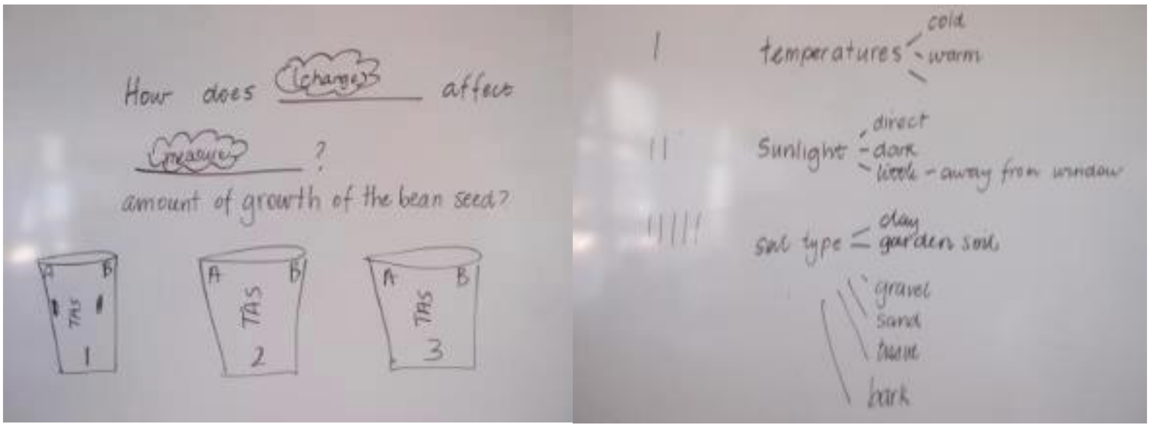
The following sections examine “Queensland” science team students’ written and oral science language resulting from Stella's scaffolding using the GRR instructional practices. The SIS Modified Solo-taxonomy was applied to transactions taken from lessons and samples of students' written work from science journals to identify evidence of students' learning. This analysis that follows in Section 5.3.5 demonstrates evidence of students in the focus group "Queensland" interacting by asking questions of each other, discussing their ideas and debating to generate joint understanding and largely demonstrating application of Science Inquiry Skills.

5.3.4 PATScience results

In the PATScience test administered prior to teaching, three of the four students (Polly, Christopher and Eliza) in the Queensland team achieved an average stanine score and one student (Peter) demonstrated an above average score of seven. The post teaching PATScience results are interesting with the two female students (Eliza and Polly) showing better achievement than the two boys by demonstrating a growth of three stanines from the average range to the high and very high range. The achievement of the two male students did not show the same growth with Peter remaining on a stanine seven and Christopher decreasing from stanine 5 to stanine 4. The assumption could therefore be made that the teaching style was more suited to female students than male students, however, a wider analysis of the whole class results indicated that this was not the case with three boys and four girls in total achieving a lower stanine after the teaching. Consequently, this raises questions about the suitability of this form of standardised testing for gaining in depth insight into the extent to which students demonstrate understanding and application of Science Inquiry Skills whilst engaged in Science Inquiry.

5.3.5 Student outcomes analysis of lessons

The research consisted of eight lessons, which focused on Science Inquiry Skills (SIS). Throughout the lesson sequence, Stella guided the science teams to plan and conduct a team fair test using Science Inquiry Skills. Initially the science teams were asked to make decisions about variables they would change, measure and keep the same (Cows, Moo, Softly). They were given a choice of what they could change and were provided with scaffolding and instructions enabling them to collaboratively write an appropriate investigation question. The choices of what they could change (temperature, sunlight or soil type) and an exemplar for writing an investigation question was written on the white board (Figure 5.1). The focus science team, “Queensland”, chose to change the soil type. Stella guided a whole class discussion to make decisions about what would be measured. A consensus was reached to measure the length of the stem. In this guided inquiry students were given a general question and made choices about what focus their inquiry will take, what procedure they will follow and how they will record and analyse data and present the information they’ve gathered. Stella’s intention was to prepare students for planning their own individual open inquiry the following term for the



school’s annual Science Excellence Expo.

Figure 5.1 Teacher notes on the whiteboard

Lesson Two – Observing bean seeds

A focus of lesson two was to provide hands-on shared experiences for students to explore bean seeds and teach the SIS, observation. The first activity in lesson two allowed Stella to formatively assess students’ existing understandings about seeds and involved students working in science teams to observe a bean seed and discuss whether they thought it was living or non-living. They came to a group consensus and recorded their ideas on a graphic organiser. The students in science team “Queensland” decided that a seed was living and listed the reasons for their choice (Figure 5.2), which provides evidence of students’ conceptual understandings about seeds. The purpose of this activity was to investigate the kinds of explanation that students would provide regarding the ability of a seed to germinate. The “Queensland” team provided responses ranging in level from uni-structural to relational:

Uni-structural

Responses from students included phrases such as “Makes the plant grow”, “It grows”, “It regrows”.

In each of these U1 responses the student has provided one piece of evidence explaining why a seed is living. The responses all indicate that because a seed grows it is living.

Multi-structural

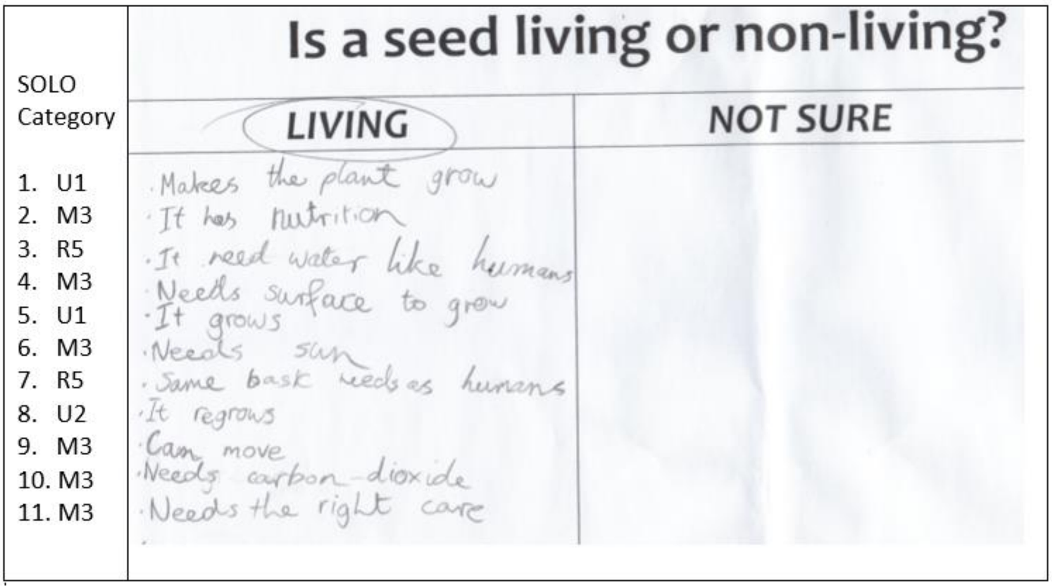
Examples from students’ responses included “Needs the right care”, “Needs a surface to grow”, “Needs the sun”, “Needs carbon dioxide”, “Can move”, “It has nutrition”.

All of these responses identify that seeds are living and also mention a relevant scientific concept in an attempt to provide some supporting evidence about the circumstances required for growth.

Relational

Needs water like humans, Same basic needs as humans

These responses go further by explaining the needs of seeds for growth and making an attempt to make comparisons to the needs of humans.



SOLO Category	Is a seed living or non-living?	
	LIVING	NOT SURE
1. U1	· Makes the plant grow	
2. M3	· It has nutrition	
3. R5	· It need water like humans	
4. M3	Needs surface to grow	
5. U1	· It grows	
6. M3	· Needs sun	
7. R5	· Same bask needs as humans	
8. U2	· It regrows	
9. M3	· Can move	
10. M3	· Needs carbon-dioxide	
11. M3	· Needs the right care	

Figure 5.2 Living or non-living graphic organiser

Next, students worked in science teams to explore conditions required for germination by making observations of a dry bean seed and a soaked bean seed and recorded their information in labelled diagrams. While they worked in science teams to discuss observations, each student completed an individual record of their observations. Examples of “Queensland” students’ descriptions and labelled diagrams provide evidence of uni-structural and multi-structural responses (Figures 5.3 and 5.4). These responses show the two students have taken a number of factors into account. They have demonstrated M3, according to the rubric by making, recording and comparing observations of a dry and soaked bean seed using knowledge of relevant science concepts. The responses in Figures 5.3 and 5.4 are representative of the analysis of the four students in Queensland science team.

SOLO Category | "Queensland" Student Graphic Organiser

1. U1

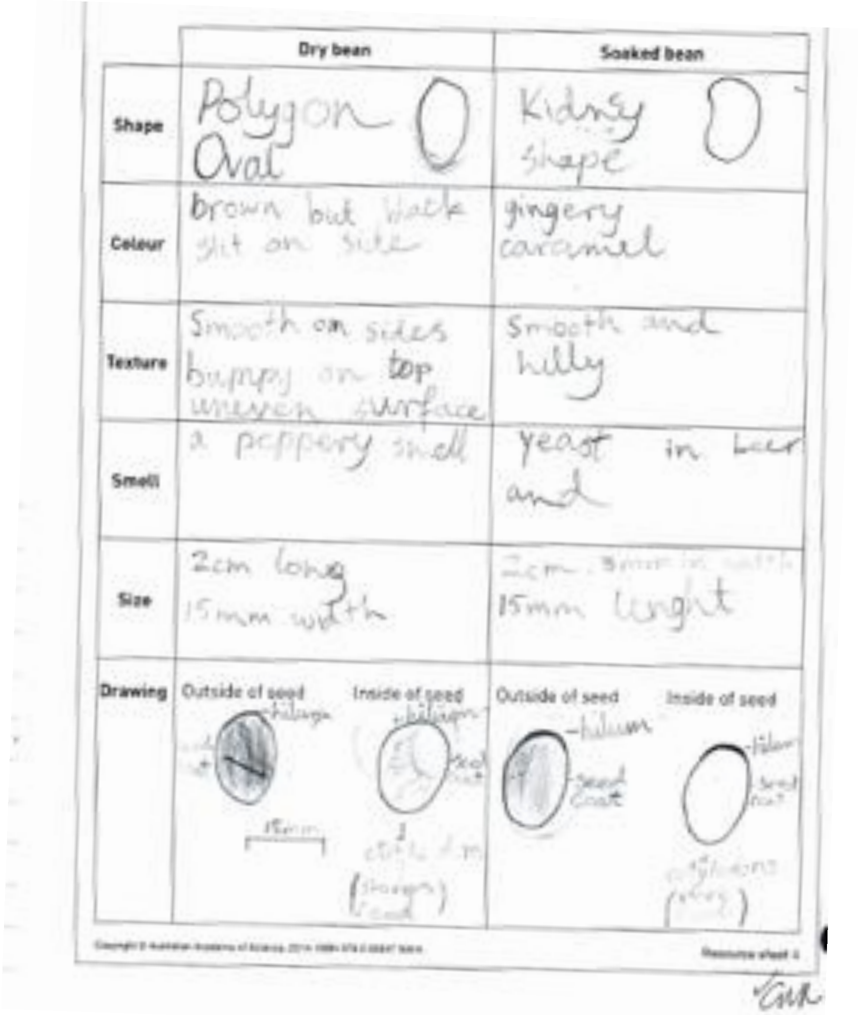
2. U2

3. M3

4. U2

5. M3

6. M3



	Dry bean	Soaked bean
Shape	Polygon Oval	Kidny shape
Colour	brown but black slit on side	gingery caramel
Texture	Smooth on sides bumpy on top uneven surface	Smooth and hilly
Smell	a peppery smell	yeast in beer and
Size	2cm long 15mm width	15mm lenght
Drawing	Outside of seed hilum; Inside of seed hilum, seed coat	Outside of seed hilum, seed coat; Inside of seed hilum, seed coat

Figure 5.3 Seed observation record by Eliza (Primary Connections, 2012)

<table>
<tr><td>SOLO Category</td><td>“Queensland” Student Graphic Organiser</td></tr>
<tr><td>1. M3

2. M3

3. M3

4. U2

5. M3

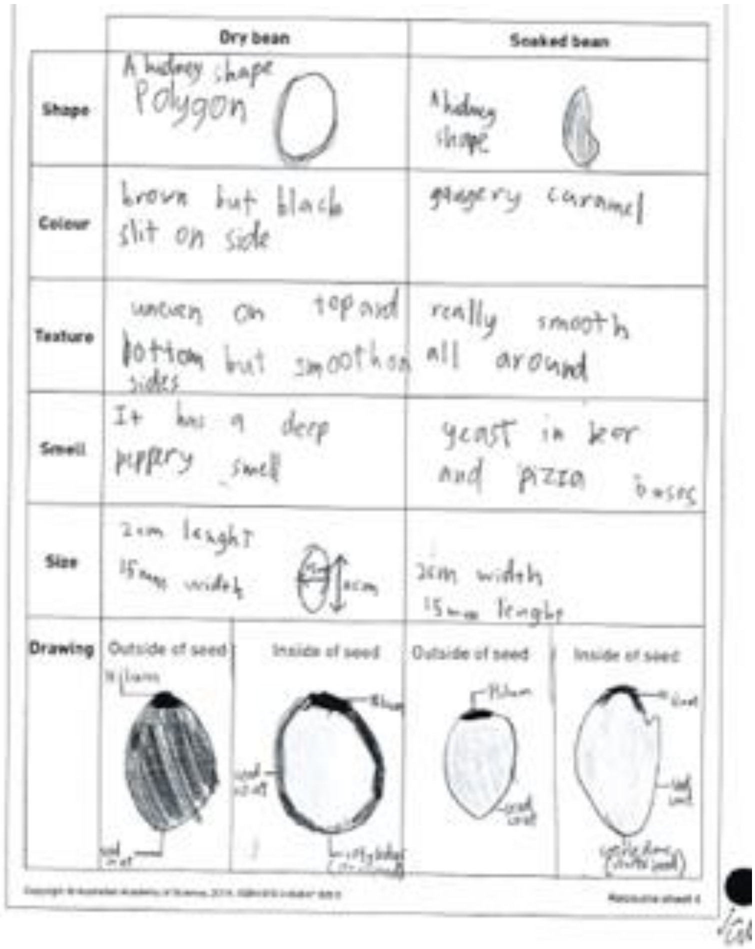
6. M3</td><td>
</td></tr>
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Figure 5.4 Seed observation record by Peter (Primary Connections, 2012)

Lesson Three – Bean seed germination in a tissue inquiry

The bean seed germination in a tissue inquiry was used to teach students the necessary Science Inquiry Skills in preparation for planning and conducting a fair test to investigate the conditions that affect plant growth. Students worked in science teams to follow a set procedure that had been demonstrated by Stella in the “I do it” phase of GRR, but each student had their own cup and beans. The task was to wrap bean seeds in tissues and place in a cup. Stella circulated around the class to scaffold students in science teams. While the majority of student responses were uni-structural, Stella asked questions about the purpose of the tissues, which encouraged some higher level responses from Peter as demonstrated by the M3 coding.

Peter	Do you squash the tissues together? (U1: Asking a question to clarify information)
Stella	Yes, you can squash the tissues together.
Peter	Cause I'm leaving mine a bit loose. (U1: Follows a procedure)
Polly	I'm putting three. (U1: Follows a procedure)
Christopher	I put four in. (U1: Follows a procedure)
Stella	Yea I put three in.
Peter	So do I have to squeeze it or could I use it a little bit loose. (U1: Asking a question to clarify information)
Stella	Um, what's the goal, what's the purpose of the tissues?
Peter	So we could see the roots growing. (M3: Justify response to a question; Communicating understanding using scientific vocabulary)
Stella	So the aim of putting the tissues in the middle is to push the roots out so we can see them. What's the other reason why we have the tissues there?
Peter	To drain the water. (M3: Justify response to a question: Communicating understanding using scientific vocabulary)
Stella	Not to drain the water but to help keep the water in there to keep them soaked isn't it? So really you want to make sure, um…
Peter	Put it where the seeds are. (U1: Responding to a question: Communicating understanding)
Stella	That's right, so that looks pretty good to me.

Figure 5.5 Queensland students discussing observations with Stella

It is important for students to experience the phenomenon of following a procedure before being released in the “You do it” phase to follow a similar procedure. This investigation provided students with scaffolded practise setting up a bean seed investigation so they were more prepared to conduct their own group fair test to investigate the conditions that affect plant growth.

After setting up the cup in lesson two students made observations of the bean plant growing in tissue over the following two weeks. They recorded them on a bean seed germination timeline in their science journal as illustrated by students from “Queensland” (Figure 5.6 and 5.7).

Figure 5.6 “Queensland” science team constructing a bean seed germination timeline

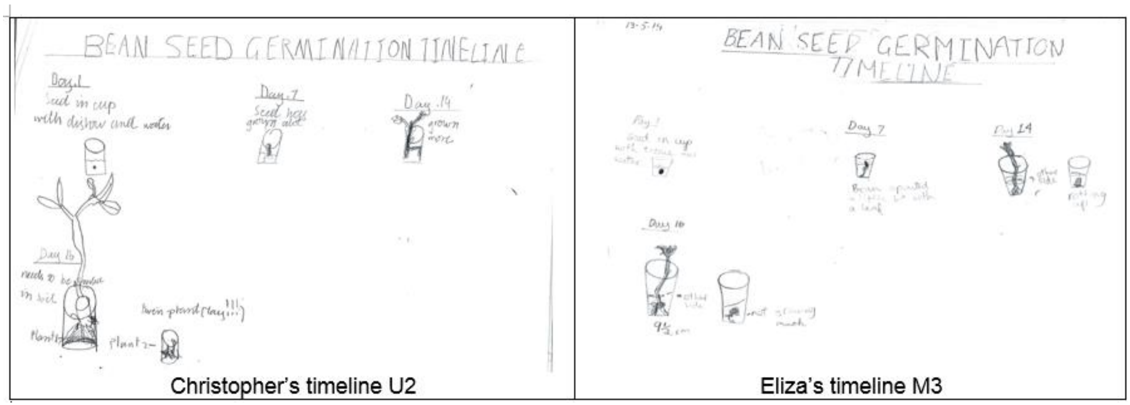


Figure 5.7 “Queensland” students’ bean seed germination timelines

Both timelines show that the students are aware of some of the stages of germination as illustrated by root, stem and leaf growth in their diagrams. Christopher’s timeline shows that he is aware of one dimension, that is, the seed has grown, making it a uni-structural response. Eliza has taken into consideration a number of factors by labelling the “sprouting leaf” on day 7 and also measuring and recording the plant growth on day 16, which makes it a multi-structural response. The modified SOLO-taxonomy provides an effective way of gauging the level of students’ responses as they communicate conceptual understandings of their bean plant observations.

Lesson Four - Planning an experiment using fair test procedures

The science teams collaboratively set up their fair test to investigate the conditions that affect plant growth during an extra session after lesson three, however this was not video or audio recorded, so by lesson four the bean seeds had germinated. The focus science team, “Queensland”, chose to change the soil type. In lesson four Stella guided the students to discuss in their teams which variables they were changing, measuring and keeping the same. The following transaction provides evidence of students in “Queensland” discussing which variable they are changing. Stella used the name of the phase, “You do it together” when giving instructions as a cue for students to engage in collaborative discussion.

Stella	Ok, so in our investigation, I want you to talk now. This is a “You do it together” task. I want you to talk in your teams and I want you to talk about what you’re changing. Ok and if you think you are doing your investigation properly. So I’m going to give you sixty seconds. Talk just about what you are changing only C please. Off you go.

(Science teams discuss in groups while teacher monitors individuals and groups)

Christopher	Alright guys, what are we changing? (U1: Asks a question to seek a solution)
Peter	We’re changing the soil type. (M3: Responds to a question about fair testing; Communicates with scientific vocabulary to communicate understandings to others)
Christopher	Yea, we’re changing the soil type. (M3: Communicates with scientific vocabulary about fair testing to others)
Peter	We’re changing the soil type and how the soil type affects the...no that’s what we’re measuring, but what we’re changing is the soil type and how it? (M4: Communicates with scientific vocabulary; Attempts to explain reasoning)

Eliza	How it makes the… (U1: Asks a question to seek a solution; Attempts to expand on another students' reasoning)
Peter	Makes the plant grow (M3: Responds to a question; Communicates with scientific vocabulary about fair testing)
Christopher	How the soil type changes the plants' growth. (M4: Makes connections between variables; Communicates with scientific vocabulary to explain reasoning)
Peter	So we have mulch and sand in that one and the other one's soil. (M3: Lists variables being changed; Communicates with scientific vocabulary about fair testing)
Christopher	Yea. (U1: Listens to others' opinions and agrees)
Peter	So it may make the life cycle longer or shorter. (R5: Makes connections between variables to make a prediction; Communicates with scientific vocabulary to explain reasoning)
Polly	Yea (U1: Listens to others opinion and agrees)
Eliza	Yea (U1: Listens to others opinion and agrees)
Christopher	I think the mulch will grow the best (M3: Makes a predication)
Eliza	I think the garden soil (M3: Makes a prediction)
Polly	The sand, the sand, I looked at the sand. The sand's growing the best. (M4: Makes observations; Makes some connections between soil type and growth)
Christopher	The sand's too compressed. (R5: Communicates with scientific vocabulary; Justifies response with evidence)
Eliza	The sand's growing the best 'cause it's got a leaf already. (M4: Makes an observation; Justifies response with evidence)
Christopher	So you think the sand's going to help the growth of the plant? (M3: Asks a question about prediction to expand knowledge and clarify information)

Polly Yea. (U1: Responds to a question)

Peter I think the garden soil (M3: Makes a prediction)

Polly Yea, cause lots of grass grows on sand though. (R5: Makes connections about observations and real world example)

Peter, Christopher

Yea. (U1: Listens to others' opinions and agrees)

Christopher Yea, especially in deserts. (R5: Elaborates on ideas; Makes connections with real world example)

Eliza Yea. (U1: Listens to others' opinions and agrees)

In this transaction Stella's instructions and initial question were important for establishing the purpose of the group discussion; however, this was preceded by the "We do it" phase. In this phase Stella explicitly taught the Science Inquiry Skills required for students to engage in the collaborative discussion. She revised the skill of observation and, in doing so, referred to the observation poster as a visual cue and taught students how to do a fair test using the "Cows Moo Softly" procedure (Appendix Three). During the group discussion Stella circulated around groups and scaffolded productive group work. The students in the "Queensland" team co-constructed new meaning to answer the question posed by Stella.

> Ok, so in our investigation, I want you to talk now. This is a "You do it together" task. I want you to talk in your teams and I want you to talk about what you're changing. Ok and if you think you are doing your investigation properly. So I'm going to give you sixty seconds. Talk just about what you are changing only C please. Off you go.

This is evidenced when Eliza started to consider the effect of changing the soil types as suggested by Christopher, "How it makes the …." This is a uni-lateral response. Christopher responded with a multi-structural response, "Yes, we're changing the soil type". Christopher's reply suggests a good understanding of the purpose of the task. Peter elaborated on Christopher's explanation with a multi-structural response in an attempt to predict possible outcomes, “Makes the plant grow”. The debate continued with Eliza firming up on their prediction, followed by Polly providing some evidence supported with an observation, “The sand, the sand, I looked at the sand. The sand’s growing the best” (multi-structural response). Christopher rebutted Polly’s suggestion and justified his response with an observation of the sand, “The sand’s too compressed”. In this transaction the responses indicated that a number of factors are being taken into consideration and being related to each other varying in sophistication from U1 to R5.

The social interaction between students allowed them to scaffold each other’s learning and co-construct relational responses, for example, “Yea, cause lots of grass grows on sand though” and “Yea, especially in deserts”. The group context provided the opportunity for students to combine and splice ideas together to make reasoned conclusions in an attempt to relate the different variables involved in their explanations. In such a way, it reflects the co-construction of ideas (Vygotsky, 1978).

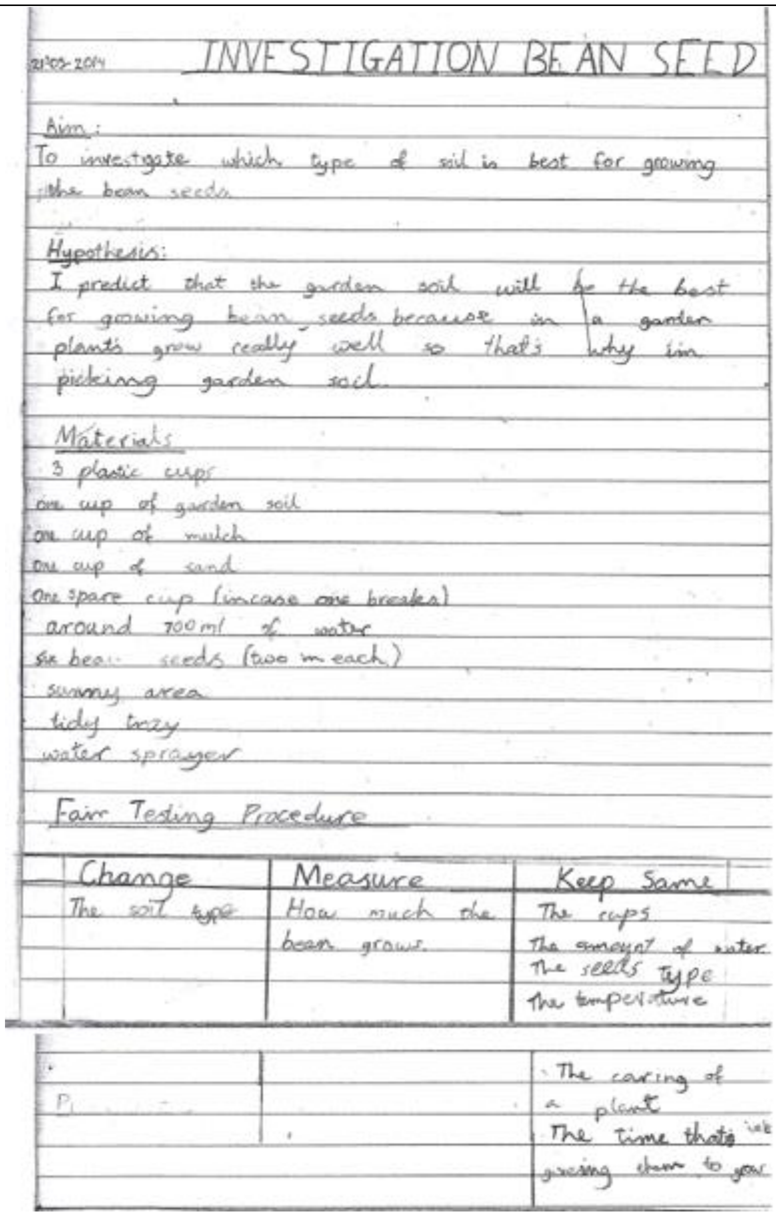
Each science team worked collaboratively to plan a bean seed investigation. Eliza’s science journal (below) is representative of the “Queensland” science team as all students worked together to co-construct the investigation plan. While working together to generate a joint investigation students recorded the investigation in their own science journal, which meant that their hypotheses, discussions and conclusions could be individualised.

R5: Communicates with scientific vocabulary to explain aim of investigation.

R5: Makes a prediction; Explains possible reason for prediction.

M3: Lists materials; Provides details.

M4: Lists variables that are changed, measured and kept the same.



21-05-2014 INVESTIGATION BEAN SEED

Aim:
To investigate which type of soil is best for growing the bean seeds

Hypothesis:
I predict that the garden soil will be the best for growing bean seeds because in a garden plants grow really well so that's why i'm picking garden soil.

Materials
3 plastic cups
one cup of garden soil
one cup of mulch
one cup of sand
One spare cup (incase one breaks)
around 700 ml of water
six bean seeds (two in each)
sunny area
tidy tray
water sprayer

Fair Testing Procedure

Change	Measure	Keep Same
The soil type	How much the bean grows.	The cups The amount of water The seeds type The temperature The caring of a plant The time thats we giving them to grow

Figure 5.8 “Queensland” student (Eliza) fair testing procedure

Most of these responses show that the students have a clear awareness of the aim of the investigation and fair testing procedures. They have considered more than one variable and made a prediction with reasoning related to observations of a real-life situation.

Lesson Four – Making observations of bean plants growing

A focus of lesson four was the SIS observation. Stella revised how to make accurate observations through modelling with think-aloud in the “I do it” phase and drew an annotated diagram of a bean plant on the white board as an example. This was followed by the “We do it” phase in which the observing poster was used as a cue to remind students of all the important aspects of making and recording accurate observations. Students then practised making and recording observations of their bean plant growing in a tissue.

Subsequently, in the “You do it together” phase (transaction below) students shared their observations of bean plants growing in different conditions (e.g. soil type, sunlight, temperature) and negotiated meaning. Stella provided clear verbal and written explanations of the types of comparisons students’ could make about the bean plants. While students worked in science teams Stella circulated around the class and guided students’ group conversations as required.

Stella:	Alright, the goal of the day is, we have talked together about the observations we can make with our plant. I want you to spend a few minutes now talking with the members of your group as a “You do it together” activity. I want you to talk about the growth of your bean seed. Ok the bean plants in front of you might want to talk about and make some comparisons between the height of the plants, the colours. Let’s record this on the board. Ok, you might want to talk about the stem height. What else could you compare? What else could you compare about your plants? Yes Polly.
Eliza	The root growth. (U2: Responding to a question; Making observations)
Stella	The root growth, yes. Ok, so we can see the root growth. What else can we see Eliza?
Eliza	The amount of leaves. (U2: Responding to a question; Making observations)
Stella	The number of leaves. What else might you be able to compare? Some plants, for example, this one. That leaf that I can see is a beautiful deep green, deep green colour whereas there are some

other ones like this one here that's been in the cupboard. That's a very pale yellow colour. Ok, so we can also make some comparisons about the colour of the stem and the leaves. So, in your science team in the next couple of minutes I want you to talk in your science team about the similarities and differences with your plants so we're making some observations. Off you go.

(Stella circulated around the class scaffolding science teams as they collaborated)

Stella Ok, some comparisons for your group. Tell me the differences please.

Christopher Well, mulch or bark um it hasn't grown a lot but if you look from the bottom you can actually see roots. (M3: Making observations; Interpreting observations; Communicating using scientific vocabulary)

Stella Ok.

Polly And that one's grown all around here. (U2: Making observations)

Peter And some of this one, you can see white. It actually stands out. (U2: Making observations)

Stella Ok, one of the other groups is using bark as well and what they found was their stem, it's sort of come round here on an angle. I wonder why, for the bark in particular that stem isn't able to grow straight up vertically.

Christopher Um because they might have put bark on the top and a lot of bark so it's not forcing its way through. It has to go to the side on its way up. (M4: Making observation; Interpreting observations)

Stella So, unlike the soil and the sand where that beautiful stem as it grows up can push the sand or the soil out of the road, perhaps what you're saying is with the bark is too bigger piece and it can't move it.

Christopher	And it’s like you can’t snap it easily. You have to kind of try hard and it’s hard for us so if it’s hard for us so a plant definitely won’t snap out of the way. (M4: Making observations; Interpreting observations)
Stella	So for your group, your predication which plant, which cup would grow the most Peter?
Peter	The garden soil. (U1: Making a prediction; Responding to a question)
Stella	The garden soil.
Peter	The garden soil, but by the looks of things, the sand is. I thought the sand would have been too much pressure. (R5: Making an observation, Justifying response to a question by communicating with scientific vocabulary)
Christopher	Too much pressure. (R5: Communicates with scientific vocabulary; Justifies reason for observation)
Stella	Much pressure.
Peter	For the seed, but it looks like the seed’s actually quite high up. (M4: Making and interpreting observations; Justifying response to a question)
Stella	What are the roots like in the sand compared with the soil?
Eliza	Well they grow all the way around there. (U1: Responding to a question; Making observations)
Polly	They’ve actually gone straight down. (U1: Responding to a question; Making observations)
Peter	They’ve gone straight down. They’ve gone all curly. (R5: Responding to a question; Making comparisons between observations)
Stella	These ones have curled around.

Christopher	It's gone like a fossil bit or? (R5: Responding to a question; Communicates with scientific vocabulary to explain possible reason for observation)
Peter	Gradually, cause these are bigger pieces. There's more gaps and the little pieces can't get in and with that there's massive pieces and the sand it can. (M4: Making an observation; Partial explanation)
Christopher	It can grow freely. What I've noticed in the sand that it's not all yellowy any more. Some of it is grey and I think that's because of the roots. (M4: Makes observations; Interprets observation by communicating with scientific vocabulary)
Stella	Ok, and the leaves, what's the comparisons, what observations can you make about these leaves here compared to the leaves in that cup and the leaves in this cup?
Christopher	Well the leaves. (U2: Mentions relevant science concept)
Peter	They look more open. (U1: Makes observations)
Stella	They're more open?
Peter	Yea, they look like they're soaked together and they're sticking together. (U2: Makes observations; attempts an explanation)
Polly	These look like a darker green. (U2: Makes observations; makes comparison)
Peter	These ones, I think these ones are kind of darker. (M4: Makes observations; attempts comparison)
Eliza	Yea, I reckon that one's dark. (U1: Makes observation)
Christopher	Those ones look a lot stronger than these. (R5: Makes comparisons between observations)
Stella	Do you think you've got a fair test there?
Students	Yea, yes, yea, yes. (U1: Responding to a question)

Stella	Ok, have a look at the height of the soil. Do you think you've got a fair test?
Eliza	No, they're not the same. (M3: Makes observations; Responding to a question about fair testing procedure)
Stella	What were you pointing at that for?
Eliza	The sand, it hasn't got as much. (M3: Makes observations; Responding to a question about fair testing procedure)
Peter	think these two are ok but? (M3: Responding to a question about fair testing procedure)
Stella	So you do you think that maybe these two have had an easier journey?
Students	Yea. (U1)
Stella	Because they haven't had to push through so much.
Peter	So these roots may be as high as that but these haven't pushed through more soil so you can't see them. (R5: Making observations; Justifying response to a question about fair testing procedure)
Christopher	Those are a lot higher than the cup. (M3: Making observations; Responding to a question about fair testing procedure)
Peter	So we can't actually judge that those are taller than those. (M3: Making a comparison about observations)
Stella	When we pull them out of the soil we'll actually be able to make some accurate measurements.
Christopher	But they're coming out of the cup more. (M3: Making comparison about observations)
Stella	That might be something when you're recording your results that you might want to make a comment on that you did have different heights in your cups. Alright, good thinking.

The students in “Queensland” science team were working in what Vygotsky describes as the Zone of Proximal Development which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky,1978, p. 86). Many of the responses in this transaction provide evidence of how questioning and commenting from the teacher can encourage the students to respond at a higher level (relational in the following case). When Stella asked the question, “So for your group, your predication which plant, which cup would grow the most Peter?” Peter responded at a uni-structural level, “The garden soil”. Stella simply restated Peter’s answer, “The garden soil” which prompted Peter to consider more contributing factors in a relational response, “The garden soil, but by the looks of things, the sand is. I thought the sand would have been too much pressure”. Peter made an observation to reflect on how his ideas had changed and justified his response by communicating with scientific vocabulary. Not only do the students demonstrate an understanding of the SIS observation, but they are communicating these observations with the use of scientific vocabulary.

Figure 5.9 “Queensland” science team discussing observations of bean plants

Lesson Five – Making comparisons of bean plant growth

Communicating with scientific vocabulary was a major focus for lesson five. In the “I do it” phase Stella explained the purpose of learning about communicating, referred to the communicating science poster and also made links with previous lessons. She used statements drawn from students’ science journals and reflective journals as examples that were not precise or accurate to show alternative scientific responses:

- Garden soil worked well
- Going great
- Off to a slow start
- Growing quite well
- Big leaves
- Pretty close
- Really huge
- Amazing results

Stella So when you’re writing up your science investigation and when you’re recording information in your science journal you need to be careful about the way you write. You have to be precise. You have to be accurate. So instead of saying something was growing huge you could say it had grown 15mm in seven days. Rather than saying "Something was off to a slow start", you could say "It had grown only 5mm in seven days".

Class Yes

Stella Is this more precise?

Class Yes

Stella Ok, instead of saying, "It was going great", you could say, "It's growing more rapidly than the other plants". (Teacher reads each example and provides a more accurate example of how to communicate)

This was followed by the "We do it" phase in which Stella explained and modelled how to do an annotated diagram. In the "You do it together" phase science teams made observations of their bean plants and recorded them with an annotated diagram. Stella circulated to monitor science teams by questioning and prompting students. Particular emphasis was placed on scaffolding students to use scientific vocabulary.

Stella Ok, so pop your pencils down cause I'd like to have a chat with you about your plants. So, tell me the difference please. Can you tell me, what are your variables?

Peter Well, I can see that this one's more compressed. (M3: Makes an observation; Communicates with scientific vocabulary to explain understanding)

Stella What are you talking about, it's more compressed?

Peter The, um sand. (U1: Responds to a question)

Stella Yes. Wasn't it the same height at the beginning? Is that what you're talking about?

Peter Na, but the sand since they're smaller grains they all bunch together harder then it's harder for the little dot to get out. (M4:

Responds to a question; Communicates with scientific vocabulary to explain possible reason)

Stella Ok.

Peter But with this you can see some small spaces inside. (Points to plant in soil) (R5: Makes and observation; Compares two observations)

Stella Mmm.

Christopher With the bark you can see that there's massive spaces because the pieces are so big. (U2: Makes an observation)

Stella This is interesting cause all of the groups that did the bark have got these roots that are really long and thin. They don't seem to be, there doesn't seem to be multiple roots from what I can see. They're all these little single roots and they just seem to run for a long distance around and around and around. Why do you think that is?

Eliza Well it's trying to spread out. (M3: Responds to a question; Attempts to explain possible reasons)

Stella The roots are trying to spread out.

Eliza Yes. (U1: Responds to a question; Reaffirms previous response)

Stella What do you think the roots are looking for? What's the purpose of roots?

Polly and Peter

Moisture. (U2: Responds to a question; Communicates with scientific vocabulary to explain possible reasons)

Stella They're looking for moisture. What else do they look for? What else do roots get for the plant? They get water. What else can they get?

Eliza Food, (pause) nutrients. (M3: Responds to a question;

Communicates with scientific vocabulary to explain possible reasons)

Stella Nutrients from the soil. So these poor plants, have you seen the leaves that have turned black? Have you seen that before?

Eliza Yea. (U1: Responds to a question)

Stella When have you seen that?

Peter Tissue one. (U1: Responds to a question)

Christopher No soil. (U2: Responds to a question; Communicates with scientific vocabulary to explain possible causes)

Stella No soil, good job so what we're seeing again is we're seeing bean seeds that have germinated and they've grown but they've got to a height but now they're looking for nutrients. Ok, they are getting water because you've been watering them regularly but they're not getting the nutrients. So these roots are search, searching for nutrients but at the same time what's happening to our plant?

Christopher It's rotting. (U2: Makes observations: Communicates with scientific vocabulary to explain possible reasons)

Eliza It's dying. (U2: Makes observations; Communicates with scientific vocabulary to explain possible reasons)

Stella This one's starting to die isn't it and if we saw it rotting it will probably go all mouldy and we saw that with some of the seeds but this isn't mouldy so I think it's just dying. Any predictions about what your plant will look like in another week when we pull them out?

Peter I think this one might be about that big because when I remember when I saw it last week it was only this big (shows with hand). (M3: Makes observation: Makes a prediction)

Eliza Yea. (U1: Listens to others' opinions; Reaffirms another students' ideas)

Stella	Ok.
Peter	But this one was roughly the same size. (U1: Makes comparisons between observations)
Stella	Ok, are we starting to see some of that black?
Polly	Yea. (U1: Listens to others opinions; Reaffirms another students' ideas)
Peter	Yea, there we can see it on all of them, there. (U1: Makes observation)
Polly	Yea, there. (U1: Listens to others opinions; Reaffirms another students' ideas)
Stella	Ok, so this one here what do you (notices student taking bark from one of the cups). Ah you're not allowed to do that. Is that a fair test? You're not allowed to move the bark on it. What's you're prediction of this one in a week's time?
Peter	Ah, I think this one will be mostly dead. (M3: Makes observation: Makes a prediction)
Stella	Mmmm and what do you think about this one?
Eliza	I think it will be a bit higher. (M3: Makes observation: Makes a prediction)
Stella	And the leaves?
Eliza	They'll be bigger. (M3: Makes observation: Makes a prediction)
Peter	Probably the same as this one (points to one of the cups) and there's a leaf coming along there (points to tiny leaf). (M3: Makes observation: Makes a prediction)
Stella	Ok, do you think this plant is going to struggle with not getting enough nutrients?
Students	Yes, yea. (U1: Listens to others' opinions; Reaffirms another

students' ideas)

Stella	So do you think that it's still going to look healthy or do you think it might start looking like this? (Teacher refers to plant in bark)
Christopher	I think it will die. Some groups are purposely drowning other group's plants. (M3: Makes observation: Makes a prediction)
Stella	Oh, so I'm looking at Christopher's hypothesis and Christopher said that he hypothesised that the plants that were growing in garden soil will be best for growing. Ok, any other ideas? Did anybody else have any other ideas or do you all think the same?
Peter	Yea, I thought that the garden soil…. (U2: Makes a prediction)
Polly	Yea, the garden soil. (U2: Makes a prediction)
Peter	I was convinced when we first started that the sand would because um these plants were just big and that one big but now that one's way bigger. (R5: Communicates to reflect on how ideas have changed; Makes observation comparing growth of plants)
Stella	Yea.
Christopher	I always thought the [inaudible]. (U1: Makes a prediction)
Polly	And I think that next week this one will be as big as this one or maybe even taller. (M3: Makes observation; Makes a predication)
Stella	Ok, is your hypothesis so far supported?
Students	Yes. (U1: Listens to others opinions; Reaffirms another students' ideas)
Stella	Probably, was that precise and accurate? Probably.
Christopher	[Inaudible].
Stella	Ok, good job.

Figure 5.10 “Queensland” science team discuss comparisons between the growth of bean plants

Throughout this transaction Stella encouraged students to explain their observations using scientific vocabulary. She was very careful not to provide too much information so the students were challenged to do the cognitive work. For example, when responding to Peter’s observation, “Well I can see that this one’s more compressed” Stella asked a question, “What are you talking about, it’s more compressed?” Subsequently with more prompting from Stella, Peter explained his understanding of compression with a multi-structural response and then made a comparison between observations of two variables, bark and sand with a relational level response, “but with this you can see some small spaces inside”.

Although the students had collaboratively discussed observations of their bean plants and recorded them in their science journals, they required adult guidance to encourage them to consider the interaction of all the contributing variables. Throughout this transaction Stella asked questions scaffolding students to reflect on their hypotheses in relation to their observations, for example, “Oh, so I’m looking at Christopher’s hypothesis and Christopher said that he hypothesised that the plants that were growing in garden soil will be best for growing. Ok, any other ideas? Did anybody else have any other ideas or do you all think the same? Polly attempted an analysis using her observations but failed to see more than one piece of evidence, “Yea, the garden soil”. Peter demonstrated a relational level response, “I was convinced when we first started that the sand would because um these plants were just big and that one big but now that one’s way bigger”. Polly made a prediction by comparing the growth of two bean plants but did not provide any reasoning for her prediction, making it a multi-structural response, “And I think that next week this one will be as big as this one or maybe even taller”. Throughout the transaction there is evidence of Stella modelling the use of scientific vocabulary, for example, “Ok, is your hypothesis so far supported?” to scaffold students to develop the ability to communicate scientifically which was the purpose of the lesson.

Lesson Six – GRR phases used interchangeably to measure bean plants accurately

Revision of the SIS measurement was the focus in lesson six to ensure students understood the importance of accurate data collection in science. This was clearly explained at the outset of the lesson and communicated on the lesson PowerPoint. Next, a strategy called “Think, Pair, Share” was used in the “We do it” phase to promote student-student discussion around the question, “Measuring accurately makes our data more reliable”. Using this strategy, the question was posed, students had time to think about it individually, and then they worked in science teams to discuss and negotiate meaning and finally share their ideas with the class.

(Science team “Queensland” discussed the question)

Peter	Ok, yes it does. You can actually remember it, if you record. So say you can’t just measure it once. You can’t say, ‘Eliza was measuring hers’. She, you know how we like take care of our own plant and we each measure our own and say, ‘This is this’. Each needs to measure each one so then we accurately record it and then discuss it. (R5: Explains how measuring accurately makes the data more reliable)
Polly	You’ve got to go over it again. (U2: Responds to a question; Mentions a procedure)

Peter	You've got to go over it and over it and double check. (M4: Builds on another students' ideas; Explains reasoning)

Stella	What do you think that statement means then?

Peter	By accurately, yea, and that makes it more accurate because you've measured it multiple times. And that will be recorded in your data, which means if you were to come along like a minute later and you had nothing and recorded it, it would probably be about the same as what we had. (R5: Explains reasons for accurate scientific measurements)

Polly	So, like you have to double check. (U2: Comments on a procedure for measuring)

(Teacher guided a whole class discussion to share ideas)

Stella	Great job. I was really impressed to come around and listen to people who were just talking about this. I was really impressed, well done. Measuring accurately makes our data more reliable, who would like to share what their group talked about, what their group said? Peter.

Peter	You can't just measure it once and trust just what somebody else says. You need to come again and measure it then measure it multiple times so it's more accurate. So if somebody else was to come along in a few minutes and do the same they will probably get the same data as you. (R5: Explains reasons for accurate scientific measurements)

Stella	Ok, so from that you're telling me that today each member of your group today is going to do the same measurements to check. Ok, is that right? (Peter nods) Ok, great idea.

Fran	If it's not accurate it's not a fair test. (R5: Explains reason for accurate scientific measurements)

Stella	Alright, can you explain a little bit more?

Fran Like if we just measured, if we measured it and then we forgot the measurements and just thought of something and just randomly wrote that down it wouldn't be accurate measurements because it wouldn't be the same as what we previously measured. (R5: Responds to a question; Explains ideas for accurate scientific measurements)

Stella Excellent, and let's add this really important word. When we go back next week, no it won't be next week it'll be the week after, and we look at our data and we draw our conclusions are they going to be reliable?

Class No. (U1: Responds to a question)

Stella No. Ok, anybody else got some different ideas?

Tanya [Inaudible]

Stella Ok, great so the way we measure is really important. Ok, if one person measures from the end of the leaf to the point where the root came out of the hilum and then the next person measured from the other end of the leaf where the stem, where the stem is at its peak, at the top, ok they would have different results. Do you agree?

Class Yes. (U1: Responds to a question)

Stella What we need to do is we have to agree today on the way we're going to measure our plants so that within your group each plant is measured the same way. That's really important information. Also something that we'll be looking at today when we're measuring is making sure we're labelling our plants, that they're all labelled correctly because that's part of the measurement process. Ok, when you're measuring each plant you want to make sure you measure Plant A from Cup 1 and you're recording, you're matching up the same in the table otherwise your data is not going to be reliable. So that's what we're going to look at.

Peter and Fran demonstrated a good understanding of the purpose of measuring accurately in relational level responses, for example, “If it’s not accurate it’s not a fair test” and “You can’t just measure it once and trust just what somebody else says. You need to come again and measure it then measure it multiple times so it’s more accurate. So if somebody else was to come along in a few minutes and do the same they will probably get the same data as you”.

Following the ‘Think, Pair, Share’ activity Stella explicitly modelled how to measure and label the bean plants accurately as well as record results. At the conclusion of this “I do it” phase she explained the purpose of her demonstration:

Stella I know that if my results aren’t recorded properly it’s going to have a huge impact on the way I analyse my data and the conclusions that I draw so I want to make sure that this is a really important stage today. That’s why we’ve spent so much time on this. Ok, so that’s an “I do it”.

The “I do it” phase was followed by the “We do it” phase in which Stella provided very explicit instructions and again referred to the GRR phases by name as well as their purpose.

Stella Ok, we’re going to do a “We do” activity now. So, one person in the group is going to cut up this and then you’re going to hand it to other members of the group. We’re going to do one together and then I’m going to let you go off and do one as a “You do together” in your group. So we’re going to do one as a ‘We do’ to make sure you’re on track with labelling and then you can do the other as a “You do it together”.

Stella systematically stepped the students through the process, monitored science teams and provided feedback to students as they removed plants from cups and labelled them. After four minutes of monitoring Stella indicated that she was not satisfied with the way students were ruling up their tables to record the results so stopped the lesson and reverted to an “I do it” to demonstrate how to draw a table again. To do this she used a student’s science journal that was projected onto the interactive whiteboard for all to see. Before proceeding to the next phase Stella asked the students to indicate if they were confident to measure the rest of the bean plants as a “You do it together” activity before she released the responsibility. This extra scaffolding combined with the teacher’s formative assessment demonstrates the flexibility of the GRR for modulating teaching. By repeating the phases of the GRR more than once in the lesson sequence, monitoring student learning and providing feedback Stella ensured the students were skilled to work collaboratively in their science teams to apply the SIS. The collaborative learning phase of the GRR (You do it together) provided a framework for students to refine their thinking about new concepts and skills and engage in social and academic interaction. The group context also provided a forum for the development of students’ scientific oral language development.

Lesson Seven - Measuring bean plants accurately

Lesson seven was a continuation of lesson six after the lunch break. The following transaction provides evidence of students in the science team “Queensland” working together to measure their bean plants and record the results in a table to apply the Science Inquiry Skill, measurement. During this “You do it together” phase individual students encouraged and facilitated each other’s efforts to complete the measuring task and achieve the group’s goals.

Christopher	So what’s that? (U1: Discusses procedure)
Eliza	Eight, yea eight centimetres. Ok, plant A. (M3: Makes accurate scientific measurements; Records results)
Peter	So cup two Plant A is eight centimetres. (M3: Makes accurate scientific measurements; Records results)
Eliza	Plant A.
Peter	Yea, cup two plant A is eight centimetres. (M3: Makes accurate scientific measurements; Records results)
Polly	And plant B of cup two is ten centimetres. (M3: Makes accurate scientific measurements; Records results)

Stella	Make sure you're agreeing on how you're going to check your answers please (speaking to whole class).
Christopher	That's what I had. (U1: Reaffirms accurate scientific measurement)
Polly	Ten centimetres. I need to write mine down so Peter you do the next one. (M3: Discusses procedure; Records results)
Peter	What was that? Cup two plant what? Which one did you just measure, cup two what? (U1: Asks a question to clarify information)
Christopher	Cup two. (U1: Responds to a question)
Peter	Yea, cup two what? (U1: Asks a question to clarify information)
Eliza	Plant B. (U1: Responds to a question)
Peter	Ok.
Eliza	Ten centimetres. (M3: Makes accurate scientific measurements; Records results)
Peter	Ok, we're not doing it yet. (U1: Discusses procedure)
Christopher	I know but I've already done one by accident. I'm just starting at the plant. (U1: Discusses procedure)
Peter	Ok, so I'm going to measure (measures a plant). (U1: Discusses procedure)
Eliza	Thirteen point seven, thirteen and a half it's plant B. (M3: Makes accurate scientific measurements; Records results)
Peter	Fourteen centimetres and that is plant A, cup three. Plant A cup three did I just say? (M3: Makes accurate scientific measurement; Asks a question to clarify information)
Eliza	Yea. (U1: Responds to a question)
Polly	What fourteen? (U1: Asks a question to clarify information)

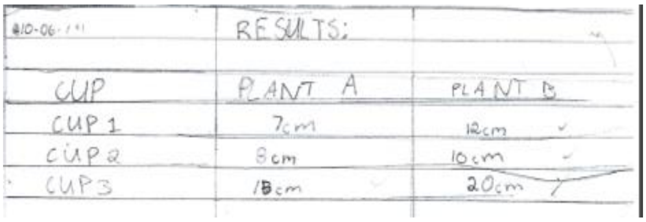
Peter	Plant A, cup three. (U1: Responds to a question)
Christopher	Ok, now this one. (U1: Discusses procedure)
Eliza	No, start it here (referring to position of tape measure). (M3: Gives instructions to another student about how to measure accurately)
Christopher	Eliza I'll take these behind me you take those (referring to plants they will take home after investigation is finished). (U1: Discusses procedure)
Eliza	Fine. (U1: Discusses procedure)
Peter	Twenty centimetres. That is cup B. (M3: Makes accurate scientific measurements; Records results)
Eliza	Plant B you mean? (U1: Asks a question to clarify information)
Peter	Yep. (U1: Responds to a question)
Eliza	I'm doing the next one. (U1: Discusses procedure)
Peter	No you're not someone else can. (U1: Discusses procedure)
Christopher	Ok, now these ones. (U1: Discusses procedure)
Polly	I'm doing it. (U1: Discusses procedure)
Peter	Seems like the soil's much [inaudible]. (U1: Makes an observation)
Christopher	What are you doing? (U1: Asks a question to clarify information)
Eliza	Putting it in the cup. (U1: Responds to a question)
Christopher	Not yet. (U1: Debates procedure)
Eliza	We've done them though. (U1: Debates procedure)
Peter	Oh yep. Guys we need it in the cup so we can take it out to be photographed by the teacher). (U1: Debates procedure;

Justifies reasoning)

Polly	Yes. (U1: Listens to others opinions and agrees)
Christopher	Oh my goodness there's lots and lots of dirt in this filmy thing. (U1: Makes an observation)
Eliza	Oh there's really lots of sand so [inaudible]. (U1: Makes an observation)
Polly	Twelve centimetres. (M3: Makes accurate scientific measurements; Records results)
Christopher	Cup one, plant B? (U1: Asks a question to clarify information)
Polly	Plant B. (U1: Responds to a question)
Peter	Twelve centimetres? (U1: Asks a question to clarify information)
Polly	Yep. (U1: Responds to a question)
Peter	Is that B? (U1: Asks a question to clarify information)
Polly	Yep. Now, plant A. (U1: Discusses procedure)

Science team "Queensland" continued to collaboratively measure their plants and recorded results in a table. When finished they took the plants outside to be photographed on the background prepared by Stella (Figures 5.11 and 5.12). Although the responses in this transaction did not progress to the more advanced relational level, the uni-structural and multi-structural responses are indicative of the extent to which students' engagement in conversation facilitated collaborative problem solving. Vygotsky's (1978) psychological model emphasises the mediating role that collaboration in a group provides for students to perform tasks, which they have not mastered independently. However, there is evidence that they understood and applied the skill of measuring during the investigation.

Figure 5.11 “Queensland” science team measuring and recording data

M3: Makes accurate scientific measurements; Records results	

10-06-14	RESULTS:	
CUP	PLANT A	PLANT B
CUP 1	7cm	12cm
CUP 2	8cm	10cm
CUP 3	18cm	20cm

Figure 5.12 Results table for “Queensland” student

Lesson Seven - You do it together recording results in a graph

After students had recorded the results in a table they worked together in science teams to graph results. Some science teams were ready to begin graphing while other science teams were still finishing off the measurement activity. Explicit teaching of graphing was planned for lesson eight so the groups that commenced graphing results in lesson seven applied prior knowledge about graphing learnt in mathematics as well as questioning skills, which were central for engagement in conversation. The following transaction provides evidence of students in “Queensland” applying the SIS questioning as they actively collaborated to construct meaning and solve problems around graphing results. Stella circulated to monitor groups as they finished off recording results and commenced graphing.

Christopher   How do you put your results on a graph? (U1: Asks a question to seek solution about graph procedure)

Peter The graph is easy. It's just like a proper graph. (M3: Responds to a question about graph procedure)

Eliza And what do you do with the [inaudible]. (U1: Asks a question to seek solution about graph procedure)

Christopher Yea, what do you do? Is it centimetres like up? (U2: Asks a question to clarify information)

Peter Well we had two plants so it's two columns. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Christopher Is it cup one, cup two, cup three?

Polly You do it down here. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Christopher I know but is that where they are? (U1: Asks a question to clarify information)

Polly No, isn't it, I don't get it. (U1: Response show confusion)

Christopher You've got to colour up to there. (M3: Responds to a question about how to accurately record scientific data in a graph)

Polly Isn't it like A, B, C, wait, wait, wait, A? (U1: Asks a question to clarify information)

Eliza Cup one, plant A. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Polly What are you supposed to, I don't get it? (U1: Asks a question to seek solution; Demonstrates confusion)

Christopher I think I'm going to put cup one, cup two, cup three and colour that cause that [inaudible]. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Peter Oh what about the centimetres? Just wait, how many centimetres are there? (U1: Asks a question to clarify information)

Christopher Um there's about ten? (U1: Asks a question to clarify information)

Eliza Wait guys we have to go up in threes, like 5, 10, 15 counting. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Polly It goes down here. (M3: Responds to a question about how to accurately record scientific data in a graph)

Christopher Yea, I'm trying to work out where they would go normally before I start colouring. (U2: Reflects on graphing procedure)

Peter You can't do ten by three. (M3: Reflects on graphing procedure to seek solution)

Eliza Wait guys, is it centimetres because if it was it would have to go up in fives. (M3: Reflects on graphing procedure to seek solution)

Polly We don't get it. (U1: Demonstrates confusion)

Peter No you go up in two's. (M3: Responds to a question with ideas about possible ways to accurately record scientific data in a graph)

Polly Oh yea.

Peter Maximum is twenty. Nothing is above twenty. (M3: Suggests possible ways to accurately record scientific data in a graph)

Eliza It's actually twenty. (M3: Responds with another possible way to accurately record scientific data in a graph)

Polly Oh yes twenty that's perfect. (U1: Listens to others opinions and agrees)

Eliza So I would say… (U1: Attempts an explanation)

Polly	Yea, it's twenty. (U1: Listens to others opinions and agrees)
Eliza	I would say go like one, two, three, four, five, six, seven. (M3: Suggests another possible way to accurately record scientific data in a graph)
Peter	You can't do ten by three you can't do it. (M4: Listens and checks other students' suggestions and debates)
Peter	You'll have to go up to eighteen if it's two. (M3: Suggests another possible way to accurately record scientific data in a graph)
Polly	No it goes up by two's. (M4: Listens and checks other students' suggestions and debates)
Christopher	No we're going to have to use the last colour or will we cut that out? (U1: Asks a question to clarify information)
Eliza	No you have to… (U1: Attempts an explanation)
Christopher	So it's cup one [inaudible] graph. (M3: Suggests a possible way to accurately record scientific data in a graph)
Eliza	Yea, let's do that. (U1: Listens to others opinions and agrees)
Christopher	Well the one that did the best is cup two. (M4: Analyses and records data)
Peter	No, cup three plant A was it? (U1: Asks a question to clarify information)
Eliza	Yea. (U1: Listens to others opinions and agrees)
Peter	And that was about 20 cm. (M3: Listens to others opinions and expands on ideas by analysing data)
Polly	Yea 20 centimetres. (U1: Listens to others opinions and agrees)
Christopher	So we can put cup 3 Plant A as the most. (M4: Records and analyses data)
Peter	Wait, no ten by six. (M3: Reflects on how ideas have changed and

suggests a possible way to accurately record scientific data in a graph)

Polly Twenty by six. (U1: Repeats others opinions)

Peter Ah you can't do that. (M3: Reflects on how ideas have changed trying to find a solution)

Christopher Oh yea. (U1: Reflects on others opinions and agrees)

Peter We might have to cut some squares out. (M3: Reflects on how ideas have changed trying to find a solution)

Polly We could do ones and that would go to ten. (M3: Reflects on others opinions and expands on ideas)

(Stella had been circulating to scaffold science teams. She noticed that science team "Queensland" needed some support.)

Stella What did you use for your intervals? (U1: Asks a question to clarify information)

Christopher Centimetres. (U1: Responds to a question)

Stella You did it in centimetres, yes but you've used a two centimetre interval?

Peter Yes. (U1: Responds to a question)

Stella What was the height of your tallest plant?

Students Twenty centimetres. (U1: Responds to a question)

Stella Oh, ok so yours is easy to work out.

Eliza Yea. (U1: Responds to a question)

Stella Ok, so that's your Y axis? What are you going to put along your X axis?

Peter Cup one, plant A. (M3: Responds to a question about recording data on a graph)

Stella	Ok.
Peter	But we don't have enough squares cause it can't be ten by six. (M3: Asks a question to seek solutions)
Christopher	Twenty by six cause there's twenty-six squares and ten across. (M4: Responds to a question and justifies reasoning)
Stella	So perhaps you could do those two together and have one space then do the next two plants together and one space. Can you do that?
Students	Yea. (U1: Responds to a question)
Peter	But then, oh yea then we'd have three. That's cool. (M3: Reflects on how ideas have changed trying to find a solution)
Stella	So that's separating cup one. Is that cup one or cup A?
Students	Cup one. (U1: Responds to a question)
Stella	Cup one, and then have a space. Cup two and then have a space, cup three.
Peter	It could be like both plants. (M3: Reflects on new ideas trying to find a solution)
Stella	Yes so you'll have two columns. So this will be cup one, plant A. This will be cup two, plant A and then we're going to have a space. Will that work?
Eliza	One, two. (U1: Reflects on new ideas)
Stella	That's ok you'll have a few at the end. This is a draught. You'll actually do your results. We'll talk about it next lesson and then we'll work from there to do your completed graph. So this is just a draught of what you're doing.
	(M4: Make accurate scientific measurements; Record results in a graph)

Again the responses in this transaction did not progress to the more advanced relational level. In this lesson students were challenged to apply a skill in a new situation. The students' uni-structural and multi-structural responses show they are attempting to work out the intervals required for constructing a graph, for example, "But we don't have enough squares cause it can't be ten by six". Many responses show that the students in "Queensland" are clearly working in Vygotsky's (1978) notion of the Zone of Proximal development, for example Peter suggested, "We might have to cut some squares out". Polly responded, "We could do ones and that would go to ten". Many responses in this transaction demonstrate students' use of questioning skills whilst collaborating in a group to perform a task they have not yet mastered independently. Eventually, Stella intervened with carefully constructed guided instruction. She helped the students get back on track by providing the appropriated scaffolds to support students in the problem solving process.

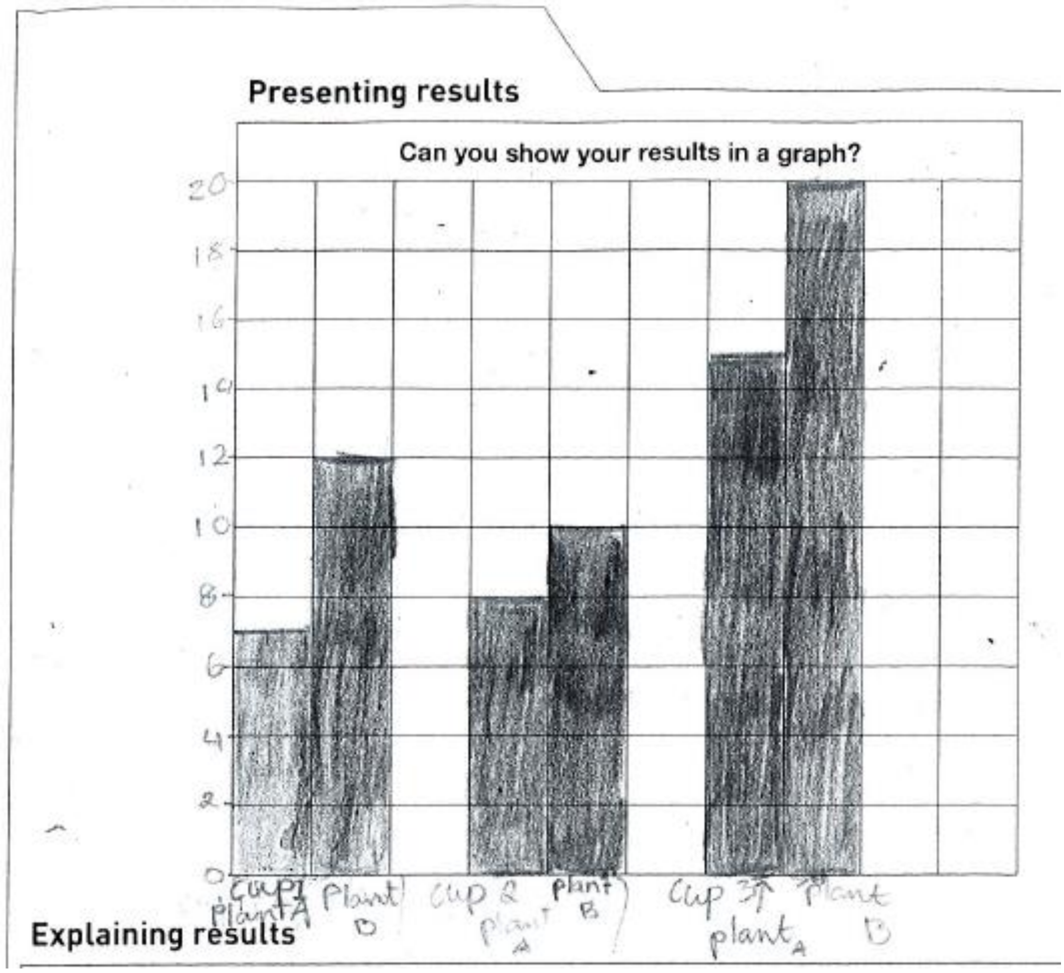


Figure 5.13 "Queensland" student's bean plant investigation graph R5

Lesson Eight – Analysing results

The focus of lesson eight was analysing data. Stella explained the purpose of the lesson:

Stella	Today we're looking at analysing data so it's actually our last lesson. So we're going to be writing our discussion and conclusion and making sure that we've done our graphs as well today. So that's where we're up to.

Next she elicited students' existing understandings about analysing data using the "Think, Pair, Share" strategy to answer the question, 'What does analysing data mean?' After this discussion Stella explicitly described in detail its meaning as she referred to cues on the lesson PowerPoint and the analysing data poster. In the "We do it" phase Stella engaged students in learning by referring to students' interests about "Deadly Animals" as a focus for analysing data asking probing questions about a set of data:

1. How was the data collected?
2. Who might have collected this data?
3. What does the term ‘analysing data’ mean?

Stella So if we have a look over at our science inquiry skills. There is a graph there just behind Peter’s head. So if we were going to look at those top 10 most deadly animals and we wanted to use that data, we could create a graph and we could analyse that data.

Stella modelled how to represent data on a graph in the “I do it” phase:

Stella This is an ‘I do it’ activity. So, ‘I do’ up in the corner (Teacher refers to PowerPoint) which means that I’m going to talk to you about my results. These are my results that I made up for my fictitious, my fake experiment and I’m actually going to talk through my ideas and what I’m thinking about my graph. So, this graph is a vertical bar graph and it represents the data from my bean plant experiment. I have a title and the title of my graph is called Plant Growth. Along the X axis I have my cups. I have Cup A Plant 1, Cup A Plant 2, then I have Cup B Plant 1, Cup B Plant 2, can you see that from up the back Ryan?

Rick Yep. (U1: Responds to a question)

Stella Yep, ok. Cup C Plant 1 and Cup C Plant 2 and of course I’ve labelled my X axis Cup and Plant. On my y axis I have a label of Height of Plant and I make sure I record the type of measurement that I’m using and in this investigation I measured the height of my plant using centimetres and I remember that from my measuring Science Inquiry Skill poster. The other important thing I had to do before I could create my graph was I had to look at the heights of my plants. Now, my tallest plant was 25cm. So what I needed to do was look at intervals in centimetres so that my highest plant could reach, would represent 25cm. So I’ve actually chosen intervals of 5cm and I've right up to 30cm. Of course, this corner here where I start, I always start at zero. So I've gone 0, 5, 10, 15, 20, 25 and 30. So that's how I've used my intervals and then I've completed my graph. So I started from the left hand side, Cup A, Plant 1 and I've recorded the measurement. I've used a ruler. Always use a ruler when I do my tables and I've gone across the page and right through to Cup C and Plant 2. Liam, do you have any suggestions? Have I missed anything in my "I do it"?

Mark No.

Stella Good, let's have a look at a "We do it".

In the "We do it" phase Stella asked for a volunteer to analyse data from a graph illustrated on the interactive whiteboard. Afterwards in the "You do it together" phase students completed their graphs.

Prior to students working together to write a discussion and conclusion, Stella modelled in the "I do it" phase how to analyse data from a graph to construct a discussion. She read aloud her own discussion as an example.

Stella We're going to move on and we're going to work on our discussion and conclusion. Then you can go back and finish your graph in your book. So, what I've got there is that's the 'I do'. That's the same graph that I showed you in the last 'I do'. Ok, it's the same title. It's exactly the same information. So I'm actually going to read you the discussion. So in your scientific report you're going to write a discussion. I'm going to read to you my discussion that talks about that information there. Ok, so while I'm reading it…this is an 'I do'. While I'm reading it you're sitting there listening. I'm modelling it for you, ok, and I want you to be having a look at the data and see if it makes sense to you because I'm not giving you the text. I'm just giving you the graph. (Stella read aloud her discussion while students listened and looked at data on the interactive whiteboard)

Finally, science teams worked collaboratively in the "You do it together" phase to analyse their bean plant investigation data and write a discussion and conclusion. Stella circulated around groups to guide instruction as evidenced in the transcription of "Queensland" below.

Stella So Peter, your plants. This one here, where was this plant? Where were these plants put?

Peter Oh they were different soil types. (U2: Responds to question about what is being changed in the inquiry)

Stella Oh yea, different soil types. So, what was this soil type?

Peter Mulch. (U1: Responds to question)

Stella So the bark and what was this soil type?

Students Sand. (U1: Responds to question)

Stella Ok, what can you tell me about your results?

Peter Um the garden soil is the biggest. (M3: Responds to question; Analyses data)

Eliza Because of the nutrients. (R5: Analyses data; Uses scientific vocabulary to explain possible reasons for data)

Polly and Eliza

Sand grew the least but shot up first. (M4: Analyses data; Explains patterns and relationships in data)

Stella And you had some interesting results with the roots didn't you?

Students Yes. (U1: Responds to question)

Stella So in your discussion you can include that as well.

Peter The sand roots were all nice and spread out and not tangled and they weren't as long as the garden soil and bark. (M4: Analyses data; Explains patterns and relationships in data)

Polly And the garden soil was just going straight down. (M3: Analyses data)

Peter The bark had the similarity to the garden soil because they would come down and at the bottom of the plastic cup they would circle around and entwine each other so it was kind of hard to measure these. (M4: Analyses data; Explains patterns and relationships in data)

Stella So the goal of our discussion is to look for patterns and relationships and not to just say this plant grew twelve centimetres, for example, that's not what we're looking for. We're wanting to see what the relationships are, what are the patterns, why you got that data. So, you think that the plants that were growing in the garden soil were the best. That was your words then Christopher. What's the evidence that you have that they grew the best?

Christopher Probably the roots. (M3: Looks for patterns and relationships in data)

Stella What were we measuring in this investigation?

Eliza and Polly

The height of the bean plant. (U2: Responds to a question about fair test)

Stella So they had the longest stem and tell me about the leaves of these plants as well.

Christopher Extremely green. (U2: Responds to a question; Explains observations)

Stella And they were a mature leaf or just a tiny leaf starting to grow.

Christopher They were really big covering the sand. (M3: Responds to a question; Explains observations)

Stella Ok, so that's what you're going to write in your discussion. That's what you're explaining. This one here, which one is this? Is this

	the one in sand? Ok, what can you tell me about those plants?
Christopher	Small leaves just sprouting at the top. (M4: Responds to a question; Explains observations using scientific vocabulary)
Stella	Ok, but they were the first ones to shoot?
Peter	Yes. (U1: Responds to a question)
Stella	Ok, so you could make that one…
Peter	They shot up for about a week and they were growing really well but then it just stopped and it was about this size. (R5: Elaborates to explain observation using scientific vocabulary)
Stella	And was that the plant they had the little black bits?
Polly	Yea. (U1: Responds to a question)
Stella	So you could actually see that that plant was starting to die wasn't it?
Polly	And at my home where I've got the sand box, on the last day here you could see the leaves even like that but now they. (R5: Elaborates to make connections with real world example)
Peter	It was due to lack of water. (M4: Reflects on others opinions and explains possible reason for result)
Stella	Are they in soil now?
Polly	Yes. (U1: Responds to a question)
Stella	And the bark ones, they seemed to grow quite well looking at your graph.
Peter	Cause they didn't grow till the last few days. (M3: Responds to a question: Analyses data)
Stella	Ok, so they didn't grow at the same rate as these. Ok, when you're explaining your results that's what you're looking for. So you're talking about that they were the same colour but you did

see some of the leaves were starting to die towards the end. Is that right? But you also need to be talking about the height of your plants. Ok, so you need to get that finished and did you have any difficulties completing this investigation? Did you have any problems?

Peter I think there was a lack of water. (M3: Responds to a question; Explains possible reason for data)

Eliza Yea. (U1: Listens to others response and agrees)

Peter In one of the plants. (U2: Elaborates on explanation)

Stella Ok, which one was that?

Christopher I got a few. (U1: Attempts to answer question)

Peter I think it was actually the mulch. (Responds to a question)

Eliza Yea the mulch. It was just all straight to the bottom. (M3: Listens to others response; Explains possible reason for data)

Christopher We had a few problems with other groups' kids actually trying to drown. (M3: Analyses data; Explains possible reason for data)

Peter Yea, they were trying to drown our plants. (U2: Listens to others opinions and agrees)

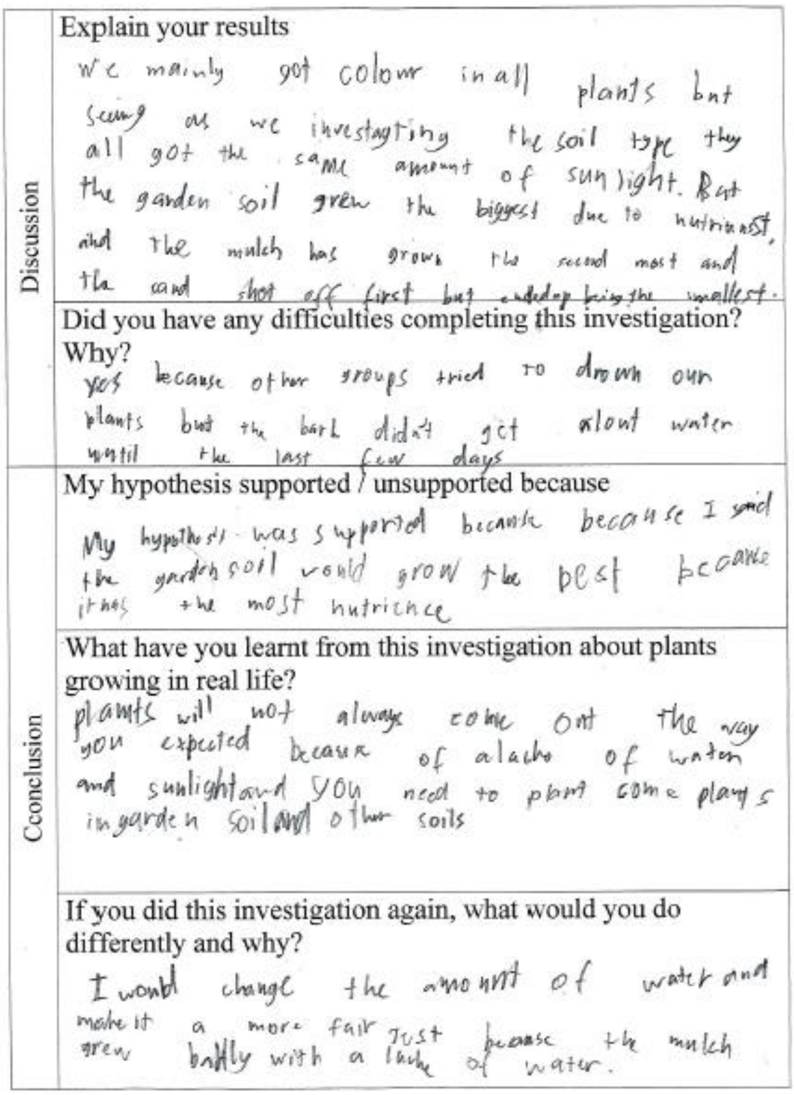
Stella Ok, so you can include that in your difficulties as well.

Figure 5.14 “Queensland” science team analysing data in the “You do it together” phase.

Figure 5.15 Stella guiding data analysis discussion with “Queensland” science team

In lesson eight Stella provided modelled and guided instruction in the “I do it” and “We do it phases” on how to analyse results and write a discussion. Then, in the “You do it together” phase students engaged in student-student collaborative dialogue to analyse the data they had collectively gathered but were required to record a discussion and conclusion in each of their science journals, providing for individual accountability. Whist students were engaged in this process Stella targeted specific needs through guided instruction to encourage individuals to consider the interaction of all the contributing variables.

Students' written discussions and conclusions in science journals provide evidence of learning and application of Science Inquiry Skills (Figures 5.16 and 5.17).



R5: Communicates with scientific vocabulary to explain results.	Discussion	Explain your results we mainly got colour in all plants but seeing as we investigating the soil type they all got the same amount of sun light. But the garden soil grew the biggest due to nutrinast, and the mulch has grown the second most and the sand shot off first but ended up being the smallest.
R5: Explains difficulties completing the investigation with possible reasons.		Did you have any difficulties completing this investigation? Why? yes because other groups tried to drown our plants but the bark didn't get alout water until the last few days
R5: Explains reason for supporting hypothesis.	Cconclusion	My hypothesis supported / unsupported because My hypothesis was supported becaule because I said the garden soil would grow the best because it has the most nutritnce
R5: Explains some possible reasons for plant growth.		What have you learnt from this investigation about plants growing in real life? plants will not always come out the way you expected because of alack of water and sunlight and you need to plant some plants in garden soil and other soils
M4: Attempts to explain reasons for modifications to the investigation.		If you did this investigation again, what would you do differently and why? I would change the amount of water and make it a more fair Just because the mulch grew badly with a lack of water.

Figure 5.16 Peter's discussion and conclusion

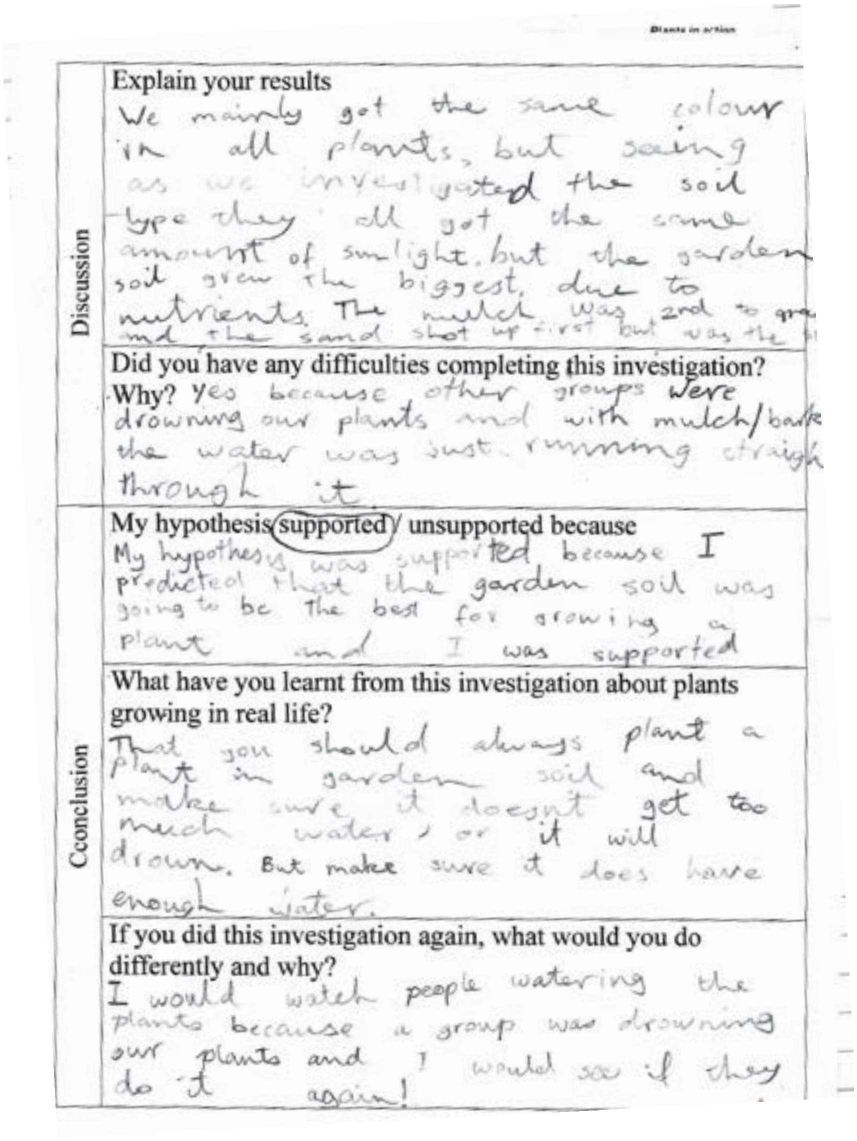
R5: Communicates with scientific vocabulary to explain results.

R5: Explains difficulties completing the investigation with possible reasons.

M4: Attempts to explain reason for supporting hypothesis.

R5: Explains some possible reasons for plant growth.

M4: Attempts to explain reasons for modifications to the investigation.



Plants in action

Discussion

Explain your results

We mainly got the same colour in all plants, but seeing as we investigated the soil type they all got the same amount of sunlight. but the garden soil grew the biggest, due to nutrients The mulch was 2nd to gro and the sand shot up first but was the

Did you have any difficulties completing this investigation? Why? Yes because other groups were drowning our plants and with mulch/bark the water was just running straigh through it.

Cconclusion

My hypothesis supported / unsupported because

My hypothesis was supported because I predicted that the garden soil was going to be the best for growing a plant and I was supported

What have you learnt from this investigation about plants growing in real life?

That you should always plant a plant in garden soil and make sure it doesnt get too much water, or it will drown. But make sure it does have enough water.

If you did this investigation again, what would you do differently and why?

I would watch people watering the plants because a group was drowning our plants and I would see if they do it again!

Figure 5.17 Eliza's discussion and conclusion

The similarity in these responses shows that the students in "Queensland" collaborated to jointly construct a discussion and conclusion. The role of peer interaction in this instance has provided a critical forum for students to combine and splice ideas together and co-construct new meanings. Both of these responses show an attempt to discuss the relationship between different variables and explain effects rather than merely to list the variables. The students have demonstrated a clear awareness of the cause and effect of sunlight on the colour of plants, "We mainly got the same colour in all plants, but seeing as we investigated the soil type they all got the same amount of sunlight". Additionally, their discussions show an attempt to explain plant growth in terms of the nutrients in soil and the amount of water required. They have both reflected on the fairness of the investigation with some reasoning and compared the results with their hypothesis. In Peter's response an explanation is provided as to why his hypothesis was supported, "because it has the most nutrients". Several of the responses are relational, having integrated two or more science concepts and SIS to explain and evaluate the bean seed investigation.

5.3.6 Student learning outcomes summary

In summary, analysis of student data sources largely determined that student-student and teacher-student discourse were fundamental for scaffolding students' learning and application of Science Inquiry Skills in each lesson. The SIS and Modified SOLO-taxonomy rubric provided a theoretical framework for determining the levels of students' understanding or competence of Science Inquiry Skills. Teacher-student and student-student dialogue in eight transactions of the "Queensland" science team collaborating to generate a joint bean seed investigation in the "You do it together" phase of instruction were analysed to ascertain the quality of students' SIS in terms of SOLO-taxonomy levels.

Data analysis revealed evidence of students in the focus group "Queensland" interacting by asking questions to each other, discussing their ideas and debating. While engaged in these processes in groups they generated joint understanding and largely demonstrated application of Science Inquiry Skills without the involvement of the teacher as evidenced in student oral discourse and written work. Throughout this productive group work student-student dialogue was predominantly uni-structural (54%) or multi-structural (43%) with minimum relational responses (3%).

However, at times Stella joined into group discussions for the purpose of checking for understanding. Examination of the breakdown of the types of responses demonstrated by students revealed that Stella's questioning, prompting and cueing enabled students to demonstrate higher level relational responses which supports the Vygotskian social constructivist perspective suggesting that the teacher's role is critical in scaffolding students' cognitive growth within the Zone of Proximal Development. During teacher-student dialogue Stella monitored students' understanding and misconceptions and extended their capability to integrate two or more science concepts and SIS thereby stimulating relational responses. Analysis of teacher-student dialogue revealed that under Stella's guidance students demonstrated approximately 48% uni-structural, 39% multi-structural and 13% relational responses. Stella's questioning, prompting and cueing facilitated a 10% increase in students' demonstration of relational responses.

Overall, just over 47% of the total student discourse and written work analysed was at the uni-structural level, 40% was multi-structural and approximately 13% was at relational level. Of significance was how students transferred what they had learnt in lessons into written work recorded in their science journals. Analysis of students' written bean seed investigations revealed 29% of responses were at the uni-structural level, 37% at the multi-structural level and 34% of written responses demonstrated students' ability to integrate two or more science concepts and SIS, making them relational.

5.3.7 Students' reflective journals and science inquiry skills survey

Additional to the eight lessons, students were provided with time to write in a reflective journal to record metacognitive thinking of their learning. Metacognitive thinking involves knowledge of cognition in general as well as awareness and knowledge of one's own cognition. The purpose of the journal was twofold; to provide Stella with evidence of students' awareness of their own learning of Science Inquiry Skills and scientific conceptual knowledge and understanding and; to gain insight into students' affective experiences of learning science. Stella used the information drawn from students' science journals to provide feedback to students and inform the planning of future lessons.

Also, a Science Inquiry Skills Survey administered at the conclusion of teaching provided further evidence of students' metacognitive thinking. A question was posed to encourage students' reflections, "How prepared or not prepared are you for doing your own experiment as a result of learning to use Science Inquiry Skills?" These responses taken together with entries drawn from the reflective journals of students in the “Queensland” science team were analysed for evidence of metacognitive thinking. Three categories of metacognitive thinking emerged from data analysis. They were students’ learning of Science Inquiry Skills, students’ scientific conceptual knowledge and understanding and, students’ experiences learning science.

Table 5.1 (below) illustrates selected comments drawn from “Queensland” students’ reflective science journals and Science Inquiry Skills Surveys revealing evidence that students in the year-4 class did indeed reflect on their own learning and were exposed to positive learning experiences of science.

Table 5.1

Selection of students’ reflective journal and SIS survey comments

Students’ learning of Science Inquiry Skills
Polly’s reflective journal 02.05.14 “This week we talked about how to write a procedure. It must include a verb at the start of each step”. 27.06.14 I have learnt about a fair test and to change one thing, measure something and keep everything else the same. I have also learnt how to measure a plant. *Christopher’s SIS survey* 11.09.15 “My science experiment was easy because our teacher goes through “I DO”, “WE DO” AND “YOU DO” a lot for, “Cows, Moo, Softly”. I think it helped me in science. “Accurate and precise measurements helped me a lot in my experiment because I had a protractor”. Recording data and using scientific language was easy because we did a lot of it in class”. “Observing wasn’t as easy as I thought it would be because our teacher doesn’t do so much of it”.

Peter's reflective journal 13.06.14 "The heights were all different. The highest was 20cm, which grew in garden soil and the shortest was 6cm, which grew in the bark. The garden soil were all the tallest plants and the bark the smallest". *Peter's SIS survey* 11.09.14 "Observing was one of my weaknesses because I couldn't make many observations on my Excellence Expo project". "I got into the hang of doing analysing, measuring and communicating because we spent a few lessons on each of them which made it easy to do in Excellence Expo. *Eliza's SIS survey* 11.09.14 "The fair test was kind of easy because we had learnt a lot about fair testing in class". "I think observing was kind of hard because everyone forgets what it is quickly so that put a bit of pressure on us". "Analysing data is when you get the results after you do your investigation. This helped me a lot because after many years I can go back and see if my results are different". "Using scientific language helped a lot of people to read and understand my science procedure. Instead of using "My prediction" I used "My hypothesis" and that's a scientific word that we have to use".
Students' scientific conceptual knowledge understanding
Eliza's reflective journal 13.06.14 "This week in science we have learnt which kind of soil would help the seed grow the most and how to look after it. I have learnt that the garden soil was the best, even though at the start it was at a slow start, and at that time the sand shot up a fair bit, the garden soil was the highest at the end. The plants were really healthy in all of the soils. It was awesome!"

Peter's reflective journal

09.04.14

"We have been learning about a plant life cycle and investigating bean seeds. There was a soaked one, which was much larger and smelt like yeast. Then there was a dry seed which was small and bumpy and smelt like dust"

Polly's reflective journal

27.06.14

"In science this term we have learnt about life and living. I have learnt that plants grow the best in garden soil and that a mosquito is the most deadly animal in the world".

Students' affective experiences of learning science

Eliza's reflective journal

02.05.14

I enjoyed this week's lesson because it was fun working with my science group.

Peter's reflective journal

02.04.14

"I really want to learn the most deadly animal on earth. I think it's the Mozzie but I want to check".

"I did enjoy working as a team because the lesson was great for team discussions".

09.05.14

"All the parts of learning about life cycles is amazing and there's so much to learn about I hope I could do this every year".

16.05.14

"I enjoyed learning about the bean seed because we stuffed in tissue and paper towel into plastic cups and placed the bean seed between the paper towel and the plastic cup to see the roots grow"

Polly's reflective journal

02.05.14

“I enjoyed this week’s lesson because it was fun working with my science group”.

16.05.14

“I enjoyed learning about how to plant seeds in a plastic cup. It was also fun working with the group”.

5.3.8 Summary

This section examined students’ metacognitive thinking about their own learning which included their attitude towards learning science. An analysis of reflections drawn from students’ science reflective journals and a survey of science inquiry skills identified written evidence of students explaining what they had learnt during the Life and Living unit, for example, “In science this term we have learnt about life and living. I have learnt that plants grow the best in garden soil and that a mosquito is the most deadly animal in the world” from Polly’s reflective journal.

Common themes emerged in the “Queensland” science team’s reflections about learning Science Inquiry Skills. Fair testing procedures were perceived to be easy due to the comprehensive learning experiences, as demonstrated in Eliza’s comment, “The fair test was kind of easy because we had learnt a lot about fair testing in class”. Christopher also thought the skill was easy and attributed his learning to the teacher’s pedagogy using the GRR, “My science experiment was easy because our teacher goes through “I DO”, “WE DO” AND “YOU DO” a lot for, “Cows, Moo, Softly”. I think it helped me in science”.

Interestingly, observation proved to be the skill that was most difficult for many of the students, as illustrated in Peter’s comment, “Observing was one of my weaknesses because I couldn’t make many observations on my Excellence Expo project”. Christopher also reflected on his difficulty making observations and accredited this to a deficit in teaching, “Observing wasn’t as easy as I thought it would be because our teacher doesn’t do so much of it”. Eliza explained her understanding of analysing data and its purpose, “Analysing data is when you get the results after you do your investigation. This helped me a lot because after many years I can go back and see if my results are different”.

Overall, data analysis revealed that students in the “Queensland” science team demonstrated metacognitive knowledge of scientific concepts and skills they had learned and the teaching and practises that helped them to learn.

In addition, attitudes towards science and interest in learning science emerged in analysis of students’ reflective journals. Statements by students in the “Queensland” science team clearly reflect an interest in learning science, for example, “All the parts of learning about life cycles is amazing and there’s so much to learn about I hope I could do this every year” and “I really want to learn the most deadly animal on earth. I think it’s the Mozzie but I want to check”. Many comments expressed an enjoyment of working in a team, for example, “I enjoyed this week’s lesson because it was fun working with my science group” and “I did enjoy working as a team because the lesson was great for team discussions”.

In summary, the students in the focus science group, “Queensland” demonstrated metacognition, in that they were mindful of their own learning and recognised the conditions under which they learned best. Examination of students’ responses also lead to the conclusion that Stella provided engaging and stimulating science-related learning activities that inspired her students to experience the joy of scientific discovery and develop their natural curiosity about the world around them.

Chapter 6 **Discussion**

6.1 Introduction

This chapter situates the major findings of this study presented in Chapter 4 within current literature pertaining to scientific literacy and instructional methods for teaching science. Specifically, the centrepiece of my research agenda is investigating Pearson and Gallagher's (1983) GRR model of instruction in which the teacher's role is to guide and structure the inquiry teaching experience to encourage, value and scaffold students' learning through four phases of instruction. The four phases, proposed by Fisher and Frey (2008) for implementing the GRR, move from modelled to guided instruction, followed by collaborative learning and finally independent experiences. The implementation of this strategy in one year-4 class is analysed through this study.

In this chapter the major findings of the study are discussed in relation to the three research questions:

1. What strategies does the teacher use to implement Science Inquiry through GRR practices in a year-4 Science class?

2. What affordances/constraints does the teacher identify in using these strategies?

3. What outcomes related to Science Inquiry Skills do students achieve as a consequence of the GRR model?

General findings are discussed emerging from the research results to answer Questions 1 and 2 (Section 6.2). Within this section, the findings are discussed in relation to pedagogical theory and the literature on scientific literacy. Question 3 (Section 6.3) addresses the implications for teaching using the GRR on student outcomes and development of scientific literacy and concludes with a summary (Section 6.4) of findings to answer the three research questions. The discussion from these three sections culminates in Section 5.5, which includes recommendations for teaching primary students to facilitate learning outcomes and positive experiences of science for establishing foundational scientific literacy development.

Two overriding assertions are tendered. Essentially, it is argued that despite the GRR model consisting of four distinct sequential phases, in this study the GRR offered a flexible pedagogical approach that helped students develop positive attitudes towards science, understand the skills of science inquiry, learn factual and conceptual knowledge and reflect on their own learning (metacognitive thinking). Subsequently, it is argued that while the GRR is seemingly a highly structured model of teaching, its success was assured through the engaging activities and rich student-student and teacher-student discourse for scaffolding students' learning and application of Science Inquiry Skills in each lesson.

Significantly, monitoring of students' science conceptual understanding and application of Science Inquiry Skills were warranted so the phases of the GRR could be adjusted to accommodate the needs of students in developing foundational scientific literacy. Explanation of these adjustments pertaining to Fisher and Frey's four-phase framework for implementing the GRR is provided.

6.2 GRR Pedagogical practices for teaching Science Inquiry Skills

In Chapter 2 current visions of scientific literacy were synthesised from the literature to identify common themes among definitions of scientific literacy. These included factual and conceptual knowledge of science, scientific inquiry, attitudes about and towards science and metacognitive thinking. The challenge faced by teachers is how to integrate these four areas. Traditionally, more emphasis is placed on teaching subject matter. Lederman and Lederman (2011) described the challenges teachers encounter when they attempt to integrate NOS and SI with science knowledge and understanding. Whether it is real or perceived, tension is created that less time is devoted to learning of the subject matter. Cognisant of this challenge, this section provides a critical examination of research question one:

What strategies did the teacher use to implement Science Inquiry through GRR practices in a year-4 science class?

The two assertions related to the strategies used for implementing GRR practices in a year-4 science classroom were supported with evidence and discussed in Chapter 4. They are:

1. Strategies were aligned with GRR model of instruction and also informed by the teacher's formative assessment of students.
2. The teacher demonstrated flexibility in time and order of the GRR phases that was influenced by teacher-student interaction for monitoring students' learning status.

In this year-4 science class, the focus was on teaching Science Inquiry Skills (SIS). The teacher's instruction using the GRR to specifically scaffold students' learning of SIS attempted to integrate SIS and conceptual knowledge. Evidence from transactions of lessons and the teacher's reflective journal revealed how Stella structured the learning environment using the four phases of the GRR that supported the scientific understanding the students were expected to develop whilst simultaneously explicitly teaching Science Inquiry Skills. A table (Appendix 8) illustrates the way in which Science Inquiry Skills became a focus for teaching in each lesson. By identifying the learning outcomes (WALT: We are learning to) and strategically planning the sequence of learning in each lesson prior to implementation, Stella determined which Science Inquiry Skills were required for students to engage in the science inquiry process as well as the best possible placement within the Life and Living science unit for teaching each skill.

Yore et al. (2007) recommend that students should develop some cognitive and metacognitive abilities and Scientific Inquiry Skills including strategies for questioning, discussion, reading and writing, evaluating scientific arguments and reasoning scientifically while engaged in processes of Scientific Inquiry. The findings from this study provide evidence of an effective pedagogical approach for implementing this recommendation. More specifically, this study identified specific teaching strategies within each phase of the GRR that were effective for teaching Science Inquiry Skills. These strategies were analysed in relation to Fisher and Frey's framework for implementing the GRR and pedagogical theory.

Many points of congruency may be found between the current study and Fisher and Frey's framework for implementing the GRR; for instance, the teacher in this study demonstrated effective strategies within the distinct instructional phases of the GRR for scaffolding students' learning which are described below. In contrast, there are clear distinctions between Fisher and Frey's model and the findings of this study. The pedagogical practices for teaching SIS to a year-4 class are described subsequently. The first assertion for answering research question one is:

Strategies were aligned with the GRR model of instruction and also informed by the teacher's formative assessment of students.

The four phases of the GRR are successively discussed in relation to the current study highlighting the strategies used by the teacher that aligned with the GRR model of instruction.

The "I do it" phase, which was the first stage in the GRR model of instruction, was marked by two key strategies; establishing a clear learning purpose for each lesson and teacher modelling of Science Inquiry Skills with think-aloud.

1. Establishing a purpose for learning was an important part of the "I do it" phase that provided students with a clear goal for learning as well as motivation for engaging in learning (Fisher & Frey, 2008; Hattie, 2012; William, 2011). The study showed that the teacher gauged students' prior knowledge and understanding in relation to the learning intent and made adjustments that catered for the individual needs of students. In this study, the teacher explicitly established a clear purpose for learning at the beginning of the lesson through the WALT (We are learning to). This occurred in the "I do it" phase to ensure students understood not only what they would be learning but also the purpose of doing particular tasks and activities in the lesson. In such a way, the teacher provided a clear learning intention as defined by Hattie (2012); that is, the learning intention provided clear information to students about the type or level of performance expected so they could evaluate their own performance in relation to achieving the learning intent. This is a strategy that Ausubel (1960) advocated over fifty years ago. The theory of advanced organisers suggests that the advanced introduction of relevant subsuming concepts (organisers) that draw upon students' existing knowledge, such as WALT in this case study, facilitates an overarching conceptual anchorage point for incorporating

unfamiliar concepts, resulting in improved learning and retention.

Furthermore, the current study revealed insight into how the teacher sought to gain an understanding of students' existing understandings so she could provide feedback to students whilst scaffolding their learning (see Section 4.2). Hattie (2012) emphasised the importance of feedback for achieving learning goals:

> If teachers can encourage students to commit to achieving these challenging goals and if they provide feedback to the students on how to be successful in learning as they work to achieve the goals, then the goals are more likely to be attained. (p. 47)

2. *Modelling with think-aloud* was used to explicitly teach each SIS. Stella did not assume that her students already knew how to perform or apply Scientific Inquiry Skills. Fisher and Frey (2008) advocate that in too many classrooms students are expected to apply skills without any instruction of "how" to perform the skills. The philosophy of teaching using the GRR acknowledges that if a learner understands the purpose of learning such as learning a science inquiry skill, and is provided with the opportunity to see it modelled by an expert, they will be able to understand and perform the skill more effectively (Fisher & Frey, 2008). The process of modelling with thinking aloud is also advocated in the work of Wood, et al., (1976) and in the cognitive apprenticeship work of Collins, Brown and Newman (1989), which is consistent with Bandura's (1997) theory of social cognition.

One example from the study occurred when Stella explained the purpose of modelling and think-aloud strategies to model the skill of observation in her reflective journal:

> Modelling expectations for students is essential and ensures students understand the task explicitly. Demonstration to observe different parts of plants in the mystery box was used to make observations of each specific item in the box, as well as "self-talk" to make links and connections between plant items in the box.

From the data analysed in the study and reflective responses such as the example above, the use of modelling with think aloud was a GRR strategy

Stella used and found valuable.

During the “I do” phase of each lesson of the GRR, the case study teacher explicitly taught and modelled Science Inquiry Skills which provided learners with information about the ways in which a skilled scientist might perform using each skill, including what they might be thinking as they performed a skill. Fisher and Frey (2012, p. 30) describe the purpose of think-aloud, “They give students the opportunity to witness how an expert merges declarative, procedural, conditional, and reflective knowledge in a fluent fashion”. In effect, what she did was model to her students an element of scientific literacy which Osborne (2007) refers to as ‘ideas-about-science’, which attempts to develop students’ understanding of both the epistemic – how we know what we know about science. Her modelling also reflected Robert’s (2007) Vision 1 of scientific literacy that proposes the role of school science is to help students develop the knowledge and skill sets that enable them to approach and think about situations in a similar way to a professional scientist.

The “I do it” phase also provided a hook to refer to later in the lesson if students needed prompting to remember the skill. Stella reflected on the benefits of scaffolding students’ learning using the phases of the GRR.

I actually love this strategy [“modelling with think-aloud”] as it provides a solid base for students to follow the task. I feel that students don’t require as much “thinking time” or “take up time” if they have first watched me undertake the task. Particularly low achieving students benefit from this method, as it provides them with more scaffolding and enables me to more efficiently “chunk” learning, for example, I might say, “Think about what was the first thing I did when I did the “I do it” or “How might you do that?” or “Show me”.The “I do it” phase of instruction was routinely followed by the “We do it” phase in which students were provided with teacher guidance and support as they attempted to apply and practise Science Inquiry Skills previously modelled and explained.

“We do it” phase strategies

Explicit explanations, questioning, prompting and *cueing* were used during the “We do it” phase for multiple purposes; to explain scientific concepts and processes, to scaffold students towards thinking more deeply about their scientific observations; to check for understanding as well as to uncover errors and misconceptions. Fisher and Frey (2008) advocate these strategies for scaffolding students' learning in the guided instruction phase of the GRR. They also align with Wood, et al.'s (1976) work on scaffolded instruction, which underpins the GRR, in that the scaffolds are slowly released as students are challenged to apply the Science Inquiry Skills in new situations. During this phase, the teacher gradually released or transferred responsibility for learning to the students.

Stella used questioning as a strategy to formatively assess students' prior knowledge and understanding to inform feedback to students and design of further follow-up in all phases of the GRR. Importantly, Stella did not limit her questioning to students who willingly offered responses but also directed her questions to students who did not put up their hands to gather some evidence of their conceptual understanding. Stella's questioning probed students about their understanding of science concepts with an emphasis on asking students to provide evidence of how they came to conclusions, for example, "How did we learn about that?" and provided important formative assessment that she used to monitor students' progress. The one-on-one transcriptions of dialogues provided evidence of the teacher asking students to elaborate or to clarify their answers to promote engagement, while providing evidence about the extent of each students' learning so that the teacher was able to adjust instruction to better meet the learning needs of her students. In addition, Stella's questioning created dialogue around reasoning, a vital skill required in science, enabling students to suggest possible scientific reasons for findings and observations (Osborne, 2007). By prompting students, asking questions about their observations, and then providing teaching at just the right moment, Stella guided her students to make connections between their observations and scientific explanations.

The interesting aspect of Stella's questioning was that she did not appear to be seeking a pre-determined right answer but encouraged students to express their opinions. That is, many students got the chance to respond or discuss a question. There are also elements in the transactions that illustrate some movement towards a dialogical type of interaction; that is, when one utterance builds on another utterance as seen in the analysis section (Section 4.2) that encouraged different perspectives. The case study teacher often acknowledged the views of others, and through student-teacher discourse, which was at times dialogic, the teacher attended to the students' points of view as well as to the school science view (Driver, Asoko, Leach, Mortimer, et al., 1994).

Most questioning was teacher initiated, followed by student response followed by another question. This discourse format is termed (Mehan, 1979) I-R-F or I-R-E bilateral mode (initiate, response, feedback or initiate response evaluate). In particular, the three-part exchange structure known as "triadic dialogue" (Lemke, 1990) or recitation has been found to be widespread in classrooms (Chin, 2006). The I-R-E discourse format in which the teacher asks a closed question that is basically information-seeking that requires a predetermined short answer has been criticised for encouraging lower-order thinking. Typically, the teacher praises correct answers and corrects those that are wrong (Chin, 2006). Ideally, a response from a student would be followed up with an extended question or an invitation to another student to comment on the response. This style of questioning would be multi-structural and encourages students to discuss their ideas openly. When Stella used this style of questioning, students' responses were multi-structural or relational, as determined by the SOLO-taxonomy (Section 5.1.4).

During the "We do it" phase in each lesson questioning was used for multiple purposes; to scaffold students towards thinking more deeply about what they were observing; to check for understanding as well as to uncover errors and misconceptions. Further discussion of students' learning in relation to the questions asked by Stella follows in "You do it together" strategies.

Cues on PowerPoint slides and SIS posters were a routine part of the "We do it" phase, providing important visual representation of the key vocabulary and concepts in relation to Science Inquiry Skills (Estes, Mills & Barron, 1969) for teaching new skills or recalling prior learning. Stella routinely directed students back to these cues to remind them of all the thinking about the Science Inquiry Skills. Graphic organisers were also used in some lessons as cues to support the learner to anticipate and organise information (Alshatti, 2011; Ausubel, 1960; Nilsson & Mayer, 2002; Novak, 2010).

Within each phase of the GRR framework, monitoring students' progress and checking their understanding was essential (Fisher & Frey, 2008). Furthermore, research has proven that the regular use of formative assessments raises academic achievement (Black, Harrison, Lee, Marshall & Wiliam, 2007). A major finding of the study was the teacher's formative assessment in the GRR phases which enabled her to monitor students' science conceptual understanding and application of Science Inquiry Skills and make adjustments to accommodate the needs of students in developing foundational scientific literacy. In the "We do it" phase of the GRR Stella used questioning, prompting and cueing through teacher-student interactions for this purpose.

"You do it together" phase strategies

Student-student and teacher-student dialogue during hands-on inquiry facilitated the learning and application of SIS in the "You do it together" phase. Through peer-peer interaction, language and discourse, students supported each other's learning (Vygotsky, 1978). Bruner's (1961) discovery learning theory encouraged the use of hands-on materials but its interpretation cast the teacher in a passive role assuming that learning occurred by individuals "trying to figure out things for oneself" (Watters & Diezmann, 1998). In the current study, student-student and teacher-student discourse in the "You do it together" phase showed a teaching approach where constructivism was a referent for practice; that is, there was a balance between teacher-student interactions and teacher-dominated conversations. This balance was demonstrated through Stella's teaching strategies where she provided opportunities for students to co-operate, develop skills in critical and creative thinking, and to explore new phenomena through which meaningful learning occurred (Watters & Diezmann, 1998). The GRR model of learning differs from traditional views of direct instruction by suggesting that "learning occurs through interactions with others, and when these interactions are intentional, specific learning occurs" (Fisher & Frey, 2008). For example, the success of small group discussion highlights the importance of student-student interactions for learning to occur. Such interactions that contributed to student learning outcomes were dependent on three important roles of the teacher: (1) introduce new ideas or cultural tools where necessary (e.g., teach the science inquiry skill) (2) provided the support and guidance for students to make sense of these themselves (teacher- student interactions), and (3) monitor students' progress and provide feedback (Stella's monitoring of progress through formative feedback) (Driver, et al., 1994; Hattie, 2012). This was supported by Stella's comments when asked, "How did you monitor students' learning within the phases of the GRR?" she responded:

> I would join in and participate in their group discussion and listen in to what they were talking about and I could ask questions during that and so that was the "You do together" phase.

In effect, students were challenged cognitively through carefully orchestrated teacher-led but not teacher-dominated discourse (Watters & Diezmann, 1998). This approach supports the Vygotskian social constructivist perspective where the teacher's role is critical in scaffolding students' cognitive growth within the Zone of Proximal Development.

"You do it alone" phase strategies

Fisher and Frey (2008) propose there are four distinct instructional stages contained within the GRR model. These include focus lessons, guided instruction, collaborative learning, and independent tasks. Many points of congruency may be found between the current case study and Fisher and Frey's (2008) framework for implementing the GRR; for instance, the first three phases are clearly represented in the teacher's lessons (Figure 6.2). A graph of the time spent on each phase in the eight lessons illustrates the presence of these three phases, but also appears to indicate the absence of the final phase of the GRR, "You do it alone". In this study, the "You do it alone" phase as defined by Fisher and Frey was absent, that is, students did not work solely on their own at any stage in this plant unit.

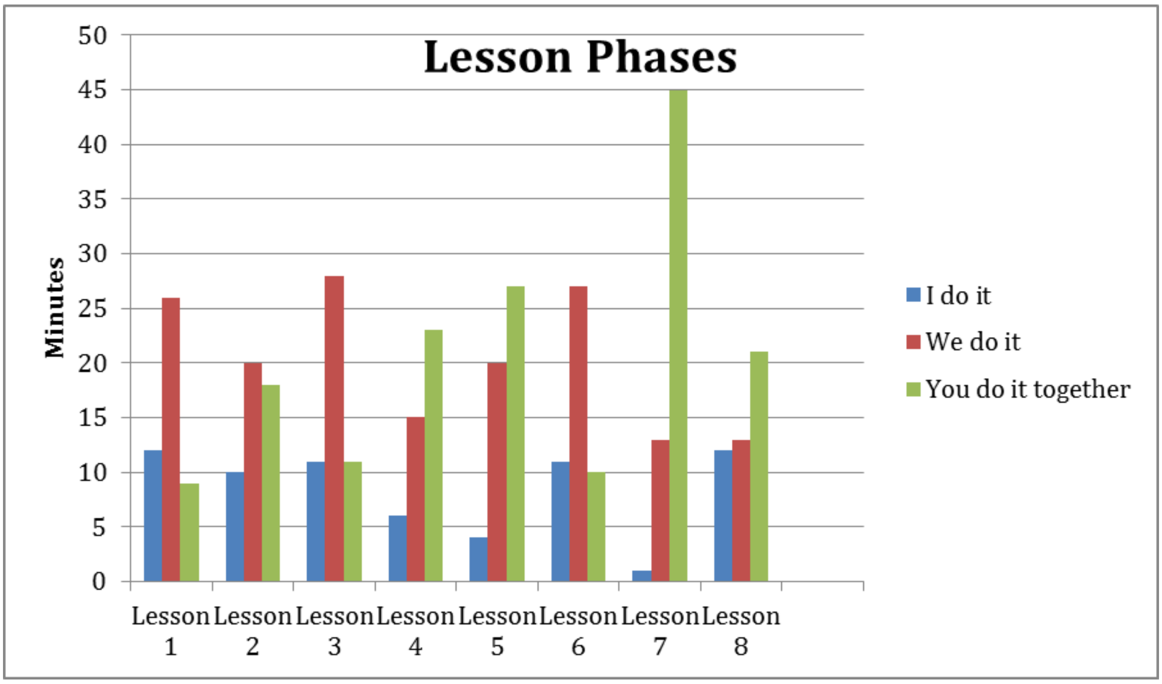


Figure 6.1 GRR lesson phases

However, the practical investigatory work that students undertook in science teams, which involved social interaction, required individuals within the groups to make sense of newly introduced cultural tools of science (i.e., SIS) and ways of viewing the world (Driver, et al., 1994). Similar to the way scientists share ideas, complement each other's work and take time to reflect on their thoughts, mental images, claims, and explanations, collaborative learning provided a framework for individual students to refine their thinking about new concepts and skills (Norris & Phillips, 2003; Yore, et al., 2004). While science teams engaged in collaborative inquiry, each student recorded his or her thinking in a science journal, providing individual accountability.

Additionally, individual science reflective journals proved to be a good way of encouraging students to use metacognitive thinking to reflect on what they had learnt during the Life and Living unit. Therefore, the "You do it alone" phase was essentially embedded within the "You do it together" phase, illustrating a point of difference between Fisher and Frey's model for implementing the GRR and the current study.

Flexibility of the GRR phases

Findings of this study contribute to arguments by Driver et al. (1994) that scientific knowledge is both symbolic in nature, for example it is populated with entities and ideas such as cotyledon, hilum, photosynthesis, phototropism and also socially negotiated, by showing that the social interaction that occurred in groups provided a forum for individuals to actively engage with others in attempting to interpret natural phenomena. In this year-4 class students were scaffolded by the teacher's use of strategies within the phases of the GRR to negotiate shared understandings of the organising concepts and associated epistemology and practices of science which, according to Driver et al. (1994), are unlikely to be discovered by individuals through their own observations of the natural world. The results align with Driver, et al. (1994) proposal that the teacher's role in scaffolding students to make sense of the ideas and practices of the scientific community is essential:

> If students are to adopt scientific ways of knowing, then intervention and negotiation with an authority, usually the teacher, is essential. Here, the critical feature is the nature of the dialogic process. The role of the authority figure has two important components. The first is to introduce new ideas or cultural tools where necessary and to provide the support and guidance for students to make sense of these for themselves. The other is to listen and diagnose the ways in which the instructional activities are being interpreted to inform further action. (p. 11)

This quote concurs with Wood, Bruner and Ross's (1976) work on scaffolded instruction where teacher-student discourse is fundamental for scaffolding a process that enables a child or novice to solve a problem, carry out a task or achieve a goal, which would be beyond his or her unassisted efforts. Significantly, the results of this study suggest that students learnt SIS through a modified GRR model. Also, the teacher used strategies that aligned with GRR suggested strategies of focused instruction (establishing a clear learning intent, modelling with think-aloud), guided instruction (questioning, prompting, cueing) and collaborative learning (student-student and teacher-student interaction, language and discourse, differentiated groups). Furthermore, the teacher monitored students' science conceptual understanding and application of Science Inquiry Skills through formative assessment and where necessary adjusted the GRR phases to accommodate the needs of students. This finding led to the second major assertion:

The teacher demonstrated flexibility in time and order of the GRR phases that was influenced by teacher-student interaction for monitoring students' learning status.

The complexity of designing collaborative learning experiences that scaffolded students to socially construct science knowledge has been explored in a number of studies (Driver, et al., 1994; Scott, Asoko & Leach, 2007; Thurston, et al., 2007; Watters & Diezmann, 1998). These studies acknowledged that the role of the primary science teacher is challenging, requiring consideration of many factors such as establishing the purpose of the activity, configuration of the groups, group accountability strategies, protocols, accommodating the needs of individuals, to mention just a few. There is a need for instructional methods that manage and modulate the information processing demands upon the teacher and learner so they are not too much or too little (Driver, et al., 1994).

The results of this study provide insight into an instructional method where students were explicitly taught Science Inquiry Skills, provided with opportunities to practise the skills with feedback from the teacher. Also, students scaffolded each other's learning with an emphasis placed on the role of peer-peer interaction, language and discourse in the development of understanding. The design of lessons using GRR phases, "I do it" and "We do it" to explicitly teach Science Inquiry Skills enabled the teacher to scaffold students' understanding of SIS. In such a way, in the "You do it together" phase, the students could work together in science teams to apply the SIS they had learnt to conduct a bean seed investigation.

The predominant pattern that emerged in analysis of the eight lessons revealed the recursive nature of the GRR where the phases were repeated more than once in the lesson sequence. This was found to be influenced by formative assessment of students' knowledge and understanding of Science Inquiry Skills identified through teacher-student interactions in the "We do it" and "You do it together" phases.

The affordances identified by the teacher were:

1. The phases of the GRR provided opportunities for the teacher to

explicitly teach SIS and scaffold students in the “I do it” and “We do it” phases.

2. The teacher’s formative assessment in the “I do it” and “We do it” phases enabled the teacher to determine students’ understanding for further follow-up in all phases.
3. The teacher’s scaffolding in the “I do it” and “We do it” phases enabled students to use SIS in the “You do it together” phase in differentiated science teams.

The purpose of teacher-student interactions in the “We do it” phase for informing future learning experiences was revealed in the teacher’s journal:

> This phase allows me to gain some knowledge of groups’ abilities to complete tasks as during the “We do it” phase, I can determine from answers and conversations in groups, who I need to follow up with and further review of measuring activities.

This statement is significant because it shows the important role the teacher placed on teacher-student dialogue for formatively assessing students’ learning status and scaffolding their developing Science Inquiry Skills. What is innovative in this thesis is that the flexible use of the GRR phases afforded the teacher opportunities to direct her attention to individuals and groups of students with greatest need.

Conversely, an analysis of the teacher’s reflective journal revealed evidence of challenges or constraints that were perceived by the teacher to inhibit or block her using the GRR as an instructional approach for teaching Science Inquiry Skills. Four categories of constraints emerged from data analysis: (1) student accountability (monitoring students during collaborative learning ensuring individual accountability and equal participation in groups), (2) time (time to conference with individual students and additional time to cover “I do it”, “We do it”, and “You do it” phases), (3) differentiation (students move through the GRR phases at different rates, lower achieving students would benefit from the ‘I do’ stage being taught at a lower level or repeated), (4) teacher talk (finding the right balance of providing adequate information in a timely manner). It was found, however, that the case study teacher adjusted her teaching to overcome many of these constraints. The four constraints are successively discussed in relation to the current study highlighting the strategies used by the teacher that aligned with the GRR model of instruction for overcoming these constraints.

(1) Student accountability

The teacher established group accountable talk protocols and also circulated to check on students' progress to ensure student accountability during collaborative learning. First developed by Resnick (1999) and subsequently described by Fisher and Frey (2008, p. 8), "accountable talk is a framework for teaching students about discourse in order to enrich these interactions". The results of this study show how the teacher explicitly taught the students protocols for group conversations that helped to overcome this constraint. They were:

- Listen when others are speaking
- Ask questions of others
- Allow "think time" after question is asked
- Criticise ideas, not people
- Listen to all ideas and discuss before deciding on one answer

The "protocols for questioning" were taught in lesson two of the science unit, reinforced in subsequent lessons and clearly outlined on the "Questioning" SIS poster. As well as being useful for facilitating productive group conversations in science, the protocols also lent themselves to other learning areas such as Mathematics and English. This was supported by Stella's comment in her reflective journal, "Having specific protocols for questioning on display in the classroom is great in science, but quite honestly I find them even more useful when working with English and Mathematics (probably because more than half my week is taken up teaching these subjects)".

These protocols helped students to listen and think deeply about the opinions of everyone in the group and stay on topic (Fisher & Frey, 2008). However, ensuring equal participation in groups also required the teacher to move around the classroom to monitor the progress of each group through questioning, prompting and cueing. From my observations, this was influenced by a positive class environment in which all students were valued and encouraged to stay on task (Hattie, 2012).

(2) Time

Stella acknowledged in her reflective journal, "Time is also a factor. By following this strategy, teachers need additional time to cover "I do it", "We do it", and "You do it" phases and this can create difficulties when attempting to complete the curriculum intent within a set time period". This statement shows that the teacher is cognisant of challenges using the GRR for teaching SIS and also teaching the science content within a set amount of time each week (one and a half hours per week). She attempted to overcome this constraint by designing lessons using the GRR phases to facilitate an integrated approach that supported the scientific understanding the students were expected to develop whilst simultaneously explicitly teaching Science Inquiry Skills (Appendix Three). While Stella strategically planned the sequence of learning in each lesson prior to implementation, her formative assessment in the "I do it" and "We do it" phases informed a flexible approach using the phases of the GRR. For example, in lesson six she realised that she had not provided enough guidance and scaffolding in the "I do it" phase to enable students to create a table to record their data. Consequently, she stopped and reviewed the skill before further releasing responsibility to the students. This recursive process is important as it indicates that the teacher was not just delivering content but monitoring learning so that students were prepared to work together in science teams to apply the SIS they had learnt to conduct a bean seed investigation.

(3) Differentiation

Stella identified differentiation as a constraint in her reflective journal, "Students move from the "You do it together" to "You do it alone" at different rates and this can be challenging". Fisher and Frey (2008) describe the three ways of differentiating instruction recommended by Tomlinson and Imbeau (2010) including content (what you teach and how students learn), process (how students think about and make sense of ideas and information) and product (how students show what they know). The results of this study provide insight into how the teacher differentiated the process.

Initially, a pre-test (Appendix Six) was administered to determine students' prior understandings and inform the differentiated groups of students according to their ability. Then, a scaffolded approach to lesson design using the phases of the GRR, and informed by the teacher's formative assessment of students, created opportunities for the process to be differentiated during the guided instruction and collaborative phases. Using the "I do it" and "We do it" phases to explicitly teach Science Inquiry Skills enabled the teacher to scaffold students' understanding of SIS. Consequently, in the "You do it together" phase, the students were able to apply the skills working together in differentiated science teams. This allowed the teacher to direct her attention to the students and groups with greatest need and provided opportunities for more independent groups to go ahead, scaffolding their own learning with peer collaboration, as demonstrated by the "Queensland" science team (Section 4.5.3). In such a way, the teacher facilitated differentiation of the process and content, as recommended by Tomlinson and Imbeau (2010). For example, Stella adjusted the questions she asked and the level of scaffolding based on the needs or strengths of the individuals and groups. She also used graphic organisers, PowerPoint slides and SIS posters as cues for providing important visual representation of the key vocabulary and concepts in relation to Science Inquiry Skills (Estes, et al., 1969) for prompting students' recall of prior learning. Throughout this process, Stella monitored students' science conceptual understanding and application of Science Inquiry Skills and made adjustments to accommodate the needs of students in developing foundational scientific literacy.

(4) Teacher talk

Stella used the phases of the GRR in attempting to overcome the constraint of too much teacher talk. She identified this constraint in her reflective journal, "Like all teachers, I am aware that we can talk too much, so finding the right balance of providing adequate information in a timely manner can be a fine line". A graph of the time spent on each GRR phase in the eight lessons (Figure 5.2) shows a relatively small amount of time was spent in direct transmission of ideas ("I do it") compared with the amount of transactional time (teacher questioning / students responding in "We do it") and student interactive time (students working in small groups in "You do it together). Overall, much of the “teacher talk” was spent scaffolding individual students and groups of students to refine their thinking about new concepts and skills.

6.3 Implications for teaching using the GRR on student outcomes

Yore et al. (2007) recommend that students should develop some cognitive and metacognitive abilities and Scientific Inquiry Skills including strategies for questioning, discussion, reading and writing, evaluating scientific arguments and reasoning scientifically while engaged in processes of Scientific Inquiry. The findings from this study provide evidence of students in science teams engaged in social and academic interaction, asking questions of each other, discussing their ideas and debating. While engaged in these processes in groups they generated joint understanding and largely demonstrated application of Science Inquiry Skills without the involvement of the teacher as evidenced in student oral discourse and written work. Analysis of student data sources determined that student-student and teacher-student discourse were fundamental for scaffolding students’ learning and application of Science Inquiry Skills in each lesson, as explained in Section 5.2.

Evidence of students working in the Vygotskyian (1978) Zone of Proximal Development (ZPD) was apparent in this study. The ZPD is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky,1978, p. 86). Significantly, the design of lessons using GRR phases, “I do it” and “We do it” to explicitly teach Science Inquiry Skills afforded the teacher’s scaffolding of students’ learning, enabling their application of SIS whilst collaborating in science teams in the “You do it together” phase.

Transactions of teacher-student and student-student discourse collaborating in the “You do it together” phase of instruction were analysed to ascertain the levels of understanding in terms of SOLO-taxonomy (Biggs & Collis, 1982, 1991). The SIS and Modified SOLO-taxonomy rubric (Table 4.4) provided a theoretically grounded framework for determining the levels of students’ understanding or competence with Science Inquiry Skills. Teacher-student and student-student dialogue in eight transactions of the focus science team collaborated to generate a joint bean seed investigation in the "You do it together" phase of instruction. These transactions were analysed to ascertain the quality of students' SIS in terms of SOLO-taxonomy levels.

Hattie (2012) describes three levels of understanding as surface, deep and conceptual in relation to the SOLO-taxonomy. However, there are four levels in the SOLO-taxonomy that can be condensed into three:

> In this [SOLO] model, there are four levels, termed "uni-structural", "multi-structural", "relational" and "extended abstract" – which simply mean "an idea", "many ideas", "relating ideas", and "extending ideas", respectively. The first two levels are about surface learning and the last two are about deeper processing. Together, surface and deep understanding lead to the student developing conceptual understanding. (p. 54)

Analysis of students' collaborative dialogue and written responses revealed uni-structural and multi-structural level responses occupied just over 47% and 40% respectively of the total student discourse and written work analysed, indicating the predominance of surface level learning. However, while only 13% were deeper level relational responses, there was a 10% increase in students' demonstration of deeper level relational responses when Stella scaffolded students' collaborative conversations with questioning, prompting and cueing. These results can be explained by considering all the learning demands placed on students as they come to terms with the epistemology (how do we know and how do we find out knowledge?) and ontology (what is the form and nature of reality and what can be known about it) of scientific social language. The students in the year-4 science class were "novice scientists" operating in the ZPD, collaborating in science teams to develop Science Inquiry Skills and to explore new phenomena and construct meaningful learning based on their prior knowledge, their current cognitive and metacognitive processes, and the classroom learning environment (Anderson & Bloom, 2001).

Significantly, analysis of teacher-student dialogue revealed that Stella's scaffolding with questioning, prompting and cueing facilitated a 10% increase in students' demonstration of deeper level relational responses. Also of significance was how students transferred what they had learnt in lessons into written work recorded in their science journals. Analysis of students' written bean seed investigations revealed 29% of responses were at the uni-structural level, 37% at the multi-structural level and 34% of written responses demonstrated students' ability to integrate two or more science concepts and SIS making them relational.

Metacognition emerged in the synthesis of scientific literacy literature as being an overarching construct. Metacognitive thinking skills identified in the synthesis of scientific literacy literature important for learning include self-reflective strategies for regulating one's own learning; critical thinking strategies for problem solving, developing and critically analysing claims, and using evidence for making reasoned conclusions; creative thinking strategies for generating and applying new ideas, identifying alternative explanations, and making new connections between learning and outcomes.

Evidence of students' metacognitive thinking skills was revealed in the analysis of student-student and teacher-student discourse and also in students' reflective journals and post-teaching survey. Students in the focus science team demonstrated aspects of metacognition as defined by Cross and Paris (1988), "The knowledge and control children have over their own thinking and learning activities" (p. 131). Researchers have recommended a number of specific instructional approaches for supporting the development of metacognition (Cross & Paris, 1988; Hennessey, 1999; Kramarski & Mevarech, 2003; Kuhn, 2000). Some of these are supported by Fisher and Frey's (2008) GRR instructional framework and were evident in the learning environment. Within the "I do it" phase Stella revealed her own metacognitive thinking-aloud which drew attention to the decision-making process. During guided instruction the teacher used questions, prompts and cues to encourage students to monitor and regulate their cognition (Lai, 2011). Collaboration in science teams promoted metacognitive discourse among students and stimulated conceptual conflict as they explained their thinking, justified claims, used evidence for making reasoned conclusions and listened to the thinking of others (Hennessey, 1999; Kramarski & Mevarech, 2003). Additionally, some students demonstrated awareness of the GRR strategies and how they influenced learning, for example, "My science experiment was easy because our teacher goes through “I DO”, “WE DO” AND “YOU DO” a lot for, “Cows, Moo, Softly”. I think it helped me in science”. All students in the focus science group demonstrated metacognitive knowledge of scientific concepts and skills they had learnt, for example, “Analysing data is when you get the results after you do your investigation. This helped me a lot because after many years I can go back and see if my results are different”.

Metacognition also entails affective and motivational states, which leads to the final aspect of scientific literacy drawn from the synthesis of scientific literacy literature (see Table 2.2). Examination of students’ responses led to the conclusion that Stella provided engaging and stimulating science-related learning activities that inspired her students to experience the joy of scientific discovery and develop their natural curiosity about the world around them. For example, students commented on the affective aspects: “I enjoyed this week’s lesson because it was fun working with my science group” and “I did enjoy working as a team because the lesson was great for team discussions”. Attitudes towards science affect students’ interest in and support for science. A relationship exists between students’ interest in science, achievement in science and future career choices. Engaging and stimulating learning experiences in science-related activities frame science as a valuable and interesting pursuit in its own right.

6.4 Summary

In addressing the three research questions of the study, evidence has been presented that in this classroom the teacher established a science learning environment characterised by strategies that were aligned with Fisher and Frey’s (2008) GRR model of instruction and also informed by the teacher’s formative assessment of students. In other ways, there were clear distinctions between the four distinct phases in Fisher and Frey’s model and the findings of this study, such as the “You do it alone” phase was essentially embedded within the “You do it together” phase.

The teacher’s scaffolding in the “I do it” and “We do it” phases enabled students to use SIS in the “You do it together” phase in differentiated science teams.

The “You do it together” phase provided a framework for individual students to refine their thinking about new concepts and skills (Norris & Phillips, 2003; Yore, et al., 2004), engage in collaborative inquiry and use metacognitive thinking to reflect on what they had learnt, explain their thinking, justify claims, use evidence for making reasoned conclusions and listen to the thinking of others. Evidence of students’ learning in the four categories drawn from the synthesis of scientific literacy literature was revealed. These included factual and conceptual knowledge of science, understanding of the processes of scientific inquiry, positive attitudes towards learning science, and reflecting on their own learning (metacognitive thinking). The teacher’s role was found to be critical in scaffolding students’ cognitive growth within the Zone of Proximal Development and application of Science Inquiry Skills.

The GRR offered a flexible pedagogical approach for supporting foundational scientific literacy development. The teacher in this case study modulated her teaching by repeating the phases of the GRR more than once in the lesson sequence. Modulation is the process in which some activity or behaviour varies in accordance with some feedback. Significantly, monitoring of students’ science conceptual understanding and application of Science Inquiry Skills were warranted so the phases of the GRR could be adjusted to accommodate the needs of students in developing foundational scientific literacy.

6.5 Recommendations for primary science education

This section will now discuss the recommendations ensuing from this thesis. Initially, six specific recommendations are made to help teachers design instructional learning experiences that help students develop foundational scientific literacy (6.5.1).

6.5.1. Recommendations for using the GRR teaching SIS

In Chapter 2 current visions of scientific literacy were synthesised from the literature to identify common themes among definitions of scientific literacy. These included factual and conceptual knowledge of science, scientific inquiry, attitudes about and towards science and metacognitive thinking. The challenge faced by teachers is how to integrate these four areas. Traditionally, more emphasis is placed on teaching science subject matter, however, Lederman and Lederman (2011) argue that the development of scientific literacy requires an individual to understand subject matter, nature of science (NOS), and Scientific Inquiry (SI). Further to this argument, they highlight the complexity of designing learning experiences that integrate these areas. “When a teacher attempts to integrate NOS and SI into instruction there is a real, or perceived, tension created that less time is devoted to the learning of subject matter” (Lederman & Lederman, 2011, p. 127).

Having considered the findings of this study I now turn to a discussion of potential ways in which teachers may design instruction using the GRR that manages and modulates the information processing demands upon the teacher and learner (Driver, et al., 1994). Six specific recommendations are proposed. They are (a) Making teachers aware of the strategies (such as questioning, prompting and cueing, etc.) within each phase of the GRR for designing lessons to facilitate an integrated approach that supports the scientific understanding developed by the students whilst simultaneously explicitly teaching Science Inquiry Skills; (b) Using the GRR phases in a nonlinear and flexible fashion so that the individual needs of students are considered; (c) Scaffolding and monitoring students’ learning and application of Science Inquiry Skills through teacher-student and student-student interaction, language and discourse; (d) Asking questions that encourage the students to respond at a higher level; (e) Using specific instructional approaches for supporting the development of metacognition (such as modelling with think-aloud); (f) Using the SIS modified SOLO-taxonomy rubric developed for this study for formatively assessing students’ responses throughout the teaching-learning cycle.

Each specific recommendation is addressed separately, although overall in the teaching and planning a primary science unit, they are all interrelated and equally important.

First recommendation: Making teachers aware of the inquiry teaching strategies

The first recommendation is that the teacher structures the inquiry teaching experience to explicitly teach and scaffold students' learning of SIS through teacher-student interactions whilst also supporting the scientific understanding the students are expected to develop through a modified GRR model. In doing so, it is recommended that the teacher think about learning in multiple ways.

(1) An initial goal for the teacher is to completely understand the science unit and the curriculum intent by referring to the Australian Science Curriculum.

(2) Next, it is important for the teacher to scrutinise and plan the proposed sequence of learning for the science unit by identifying essential content knowledge and Science Inquiry Skills necessary for students to engage in the science inquiry process. In planning the sequence of learning it is recommended that the teacher backward map from the learning outcomes students are expected to achieve so that students are explicitly taught the Science Inquiry Skills, including strategies for questioning, discussion, reading and writing, evaluating scientific arguments and reasoning scientifically, necessary for them to engage in processes of Scientific Inquiry in collaborative groups. In relation to this point, it is suggested that the teacher determine the students' prior understanding of the scientific concepts they are expected to learn as well their prior learning experiences using the Science Inquiry Skills. This formative assessment can help to inform the learning intent for each lesson (WALT: We are learning to).

(3) The final step in planning to teach a primary science unit involves understanding the phases of the GRR and strategies within each phase for scaffolding students' learning. Within the phases of the GRR, "I do it", "We do it" and "You do it together", it is important for the teacher to use the strategies that align with GRR model of instruction suggested by Fisher and Frey (2008) while being cognisant of structuring the learning environment or social context to suit the needs of the students where students are afforded opportunities to collaboratively engage in learning about science. However, flexibility in the use of these phases is encouraged.

Succinctly, the phases and strategies of the GRR are: (a) Focused instruction "I do it" (establishing a clear learning intent, modelling with think-aloud); (b)

Guided instruction "We do it" (explicit explanations, questioning, prompting, cueing); (c) Collaborative learning "You do it together" (student-student and teacher-student interaction, scientific language and discourse, differentiated groups). However, this study found that in teaching primary science the independent learning phase of the GRR can be embedded within the collaborative learning phase. The practical investigatory work that students undertake in science teams, which involves social interaction, requires individuals within the groups to make sense of newly introduced cultural tools of science (i.e., SIS) and ways of viewing the world (Driver, et al., 1994). Similar to the way scientists share ideas, complement each other's work and take time to reflect on their thoughts, mental images, claims, and explanations, collaborative learning provides a framework for individual students to refine their individual thinking about new concepts and skills (Norris & Phillips, 2003; Yore, et al., 2004). While science teams engage in collaborative inquiry, each student can record his or her thinking in a science journal or reflective journal, providing individual accountability.

Second recommendation: Using GRR phases in a nonlinear and flexible manner

Secondly, it is recommended using the GRR phases in a nonlinear and flexible fashion so that the individual needs of students are considered.

While part of the first recommendation is strategically planning the sequence of learning for each lesson prior to implementation, formative assessment can help to inform a flexible approach to using the phases of the GRR. The teacher's scrutiny of the success of his or her own teaching by way of monitoring students' progress can provide valuable information to inform the adjustment in the phases of the GRR. It is important to realise that the GRR is not a linear instructional model and the phases can be reordered or repeated within a lesson. This recursive nature of the GRR is necessary as it provides a framework for the teacher to not just deliver content but monitor and scaffold learning so that students are prepared to work together in science teams to apply the SIS they have learnt. The findings of this study concur with Driver et al's (1994) proposal that the teacher's role in scaffolding students to make sense of the ideas and practices of the scientific community is essential.

Therefore, it is recommended that teachers use strategies that align with each phase of the GRR outlined in the first proposal whilst also monitoring students' science conceptual understanding and application of Science Inquiry Skills through formative assessment. Accordingly, the teacher may choose to adjust the GRR phases to accommodate the needs of students. Moreover, the teacher's flexible use of the GRR phases afforded her opportunities to direct his or her attention to individuals and groups of students with greatest need.

Building on this recommendation, the third recommendation suggests possible ways for scaffolding and monitoring students' learning.

Third recommendation: Making teachers aware of the importance of teacher-student discourse

The third recommendation concurs with Wood, Bruner and Ross's (1976) proposal that teacher-student discourse is fundamental for scaffolding a process that enables a child or novice to solve a problem, carry out a task or achieve a goal, which would be beyond his or her unassisted efforts. This study found that students were scaffolded by the teacher's use of strategies within the phases of the GRR to negotiate shared understandings of the science concepts and associated epistemology and practices of science (SIS) which, according to Driver, et al. (1994), are unlikely to be discovered by individuals through their own observations of the natural world. The strategies that were found to be crucial in this respect were teacher-student and student-student interactions that afforded the use of appropriate language and discourse. Furthermore teacher-student interactions were found to provide many opportunities for the teacher in this study to formatively assess students' learning status and scaffold their developing Science Inquiry Skills

Related to this third recommendation, is that the teacher's questioning, prompting and cueing are important strategies for scaffolding and monitoring students' learning and application of Science Inquiry Skills. The role of the teacher during collaborative dialogue is to ask students to elaborate or to clarify their answers and promote engagement whilst remaining cognisant of maintaining a balance between teacher-student interactions and teacher-dominated conversations (Watters & Diezmann, 1998).

The students' answers to probing questions can provide evidence about the extent of their learning (formative assessment) so that the teacher is able to flexibly use the phases of the GRR to better meet the learning needs of individual students.

Also, the role of peer interaction during the collaborative learning phase is to provide a critical forum for students to combine and splice ideas together and co-construct new meanings. However, this is dependent on prior explicit teaching with scaffolded practice and teacher feedback in the focused and guided instructional phases enabling students to move from modelled to guided instruction, followed by collaborative learning and finally independent experiences.

Fourth recommendation: Making teachers aware of the important role of questioning

Previous studies have mentioned the important role of questioning for creating dialogue around reasoning, a vital skill required in science, enabling students to suggest possible scientific reasons for findings and observations (Osborne, 2007). From this study, the role of the teacher was found to be pivotal in asking students probing questions about their understanding of science concepts with an emphasis on providing evidence of how they came to conclusions. For example questions such as, "How did we learn about that?" or simply saying "Because….." prompted students to justify their responses and encouraged higher level responses, as determined by the modified SOLO-taxonomy. Ideally, a response from a student would be followed up with an extended question or an invitation to another student to comment on the response. This style of questioning would be multi-structural and encourages students to discuss their ideas openly. Also, as teachers learn to facilitate dialogical type interactions (i.e., where one utterance builds upon the other, see Section 5.1.4) within collaborative groups they may be rewarded with a range of different perspectives.

Fifth recommendation: Making teachers aware of instructional approaches for developing students' metacognition

In this study it was noted that using specific instructional approaches supported the development of students' metacognition. Additionally these instructional approaches provided the teacher with insight into students' affective experiences of learning science. Specifically, three approaches emerged from the findings of the study for supporting students' metacognitive thinking. They were: (a) Student reflective journal; (b) Teacher's modelling with think-aloud; (c) Collaboration in science teams.

Students' reflective journals provided the teacher with evidence of students' awareness of their own learning of Science Inquiry Skills and scientific conceptual knowledge and understanding. The students' reflections also allowed the teacher to gain insight into students' affective experiences of learning science, which can potentially be used to inform feedback to students and the planning of future lessons. The teacher in this case study did exactly that; she used some of the students' reflections in a lesson that scaffolded students developing understanding of data analysis.

A second specific instructional approach for developing students' metacognition supported by Fisher and Frey's (2008) GRR instructional framework was evident in the learning environment. Within the "I do it" phase the teacher revealed her own metacognitive thinking-aloud which drew attention to the decision-making process. This strategy provides the learner with the opportunity to see the SIS modelled by an expert, however during this time students are not just passively receiving knowledge but rather cognitively engaged through thinking.

Thirdly, collaboration in science teams emerged from the results of the study as a learning experience that scaffolded students to socially construct science knowledge whilst promoting metacognitive discourse among students and stimulating conceptual conflict. The teacher's role was found to be significant in providing opportunities for students to reflect on their learning and how they were constructing ideas. Through the co-operate activities students were afforded the opportunities to develop skills in critical and creative thinking, and to explore new phenomena through which meaningful learning could occur (Watters & Diezmann, 1998).

Sixth recommendation

The SIS and Modified SOLO-taxonomy rubric (Table 4.4) provided a theoretically grounded framework for determining the levels of students' understanding or competence of Science Inquiry Skills. It is important to note that in this study the SIS Modified SOLO-taxonomy Rubric (Table 4.5) was developed and applied at the conclusion of instruction. A sixth important recommendation from this study is that the SIS modified SOLO-taxonomy rubric may be used for formatively assessing students' written and oral responses throughout the teaching-learning cycle to inform feedback to students, design of further follow-up in all phases of the GRR and support the development of foundational scientific literacy.

Conclusion to section

This section presented a discussion of the major findings of the study which culminated in six recommendations. Taken together, these recommendations revealed insights into a scaffolded pedagogical model (GRR) for guiding primary science students towards developing an understanding about Scientific Inquiry leading to the foundations of scientific literacy. The initiatives from this study will help to inform the development of scientific literacy in students, a high priority for governments worldwide.

Chapter 7 **Conclusion**

In response to concerns about science education raised by recent reports on students' achievements and interest in science, this study sought to develop a potentially viable way to support teachers and students in using and understanding Scientific Inquiry as an approach for developing scientific literacy. Teachers' conceptions of planning, teaching and evaluating Scientific Inquiry is a problematic issue (Keys & Kennedy, 1999); however, in this study the strategies within the phases of the GRR provided a framework for scaffolding the development of students' SIS and scientific conceptual understanding. The challenges teachers encounter when they attempt to integrate subject matter, nature of science (NOS), and Scientific Inquiry (SI) were addressed with the proposal that through a modified GRR model of instruction teachers can structure the inquiry teaching experience to explicitly teach and scaffold students' learning of SIS while developing scientific understanding that students are expected to develop (Lederman & Lederman, 2011).

The findings of this study revealed that student-student and teacher-student discourse were fundamental for scaffolding students' learning and application of Science Inquiry Skills. Importantly, during guided instruction, there was a balance of teacher-student interactions and teacher-dominated conversations. Collaboration in science teams using Science Inquiry Skills during the "You do it together" phase of the GRR enabled students to negotiate shared understandings of the organising concepts and associated epistemology and practices of science which, which according to Driver et al. (1994), are unlikely to be discovered by individuals through their own observations of the natural world. Students were involved in a social process of collaboration in which they planned and implemented a fair test in their science teams. They made predictions, observations and accurate measurements. They recorded and analysed data about bean plant growth and communicated their findings.

In addressing the three research questions of the study, evidence has been presented that in this classroom the teacher established a science learning environment characterised by strategies that were aligned with Fisher and Frey's (2008) GRR model of instruction and also informed by the teacher's formative assessment of students. In other ways, there were clear distinctions between the four distinct phases in Fisher and Frey's model and the findings of this study, such as the "You do it alone" phase was essentially embedded within the "You do it together" phase. The teacher's scaffolding in the "I do it" and "We do it" phases enabled students to use SIS in the "You do it together" phase in science teams which were differentiated according to ability. The "You do it together" phase provided a framework for individual students to refine their thinking about new concepts and skills (Norris & Phillips, 2003; Yore et al., 2004), engage in collaborative inquiry and use metacognitive thinking to reflect on what they had learnt, explain their thinking, justify claims, use evidence for making reasoned conclusions and listen to the thinking of others.

This study contributes to the body of literature concerning pedagogical practices for teaching Scientific Inquiry in tendering a modified GRR model for structuring the development of SIS in the primary classroom (Figure 7.1). Fisher and Frey's (2008) model proposes there are four distinct instructional phases, however, the modified approach that represents the findings of this study, found that in teaching primary science the independent learning phase of the GRR can be embedded within the collaborative learning phase. Within the combined "You do it together/alone" phase student-student interaction and discourse following the "Protocols of questioning" provided a forum for students to refine their thinking about new concepts and skills (Figure 7.1). The importance of formative assessment and feedback to students in all phases of the GRR is indicated below the dotted line. The teacher's monitoring of students' science conceptual understanding and application of SIS through formative assessment was used to adjust the time and order of the GRR phases (represented with the red arrow) and accommodate the needs of students. This modified model will be useful for the professional development of practicing and pre-service teachers when introducing the GRR as one possible model for scaffolding Science Inquiry Skills in the primary years.

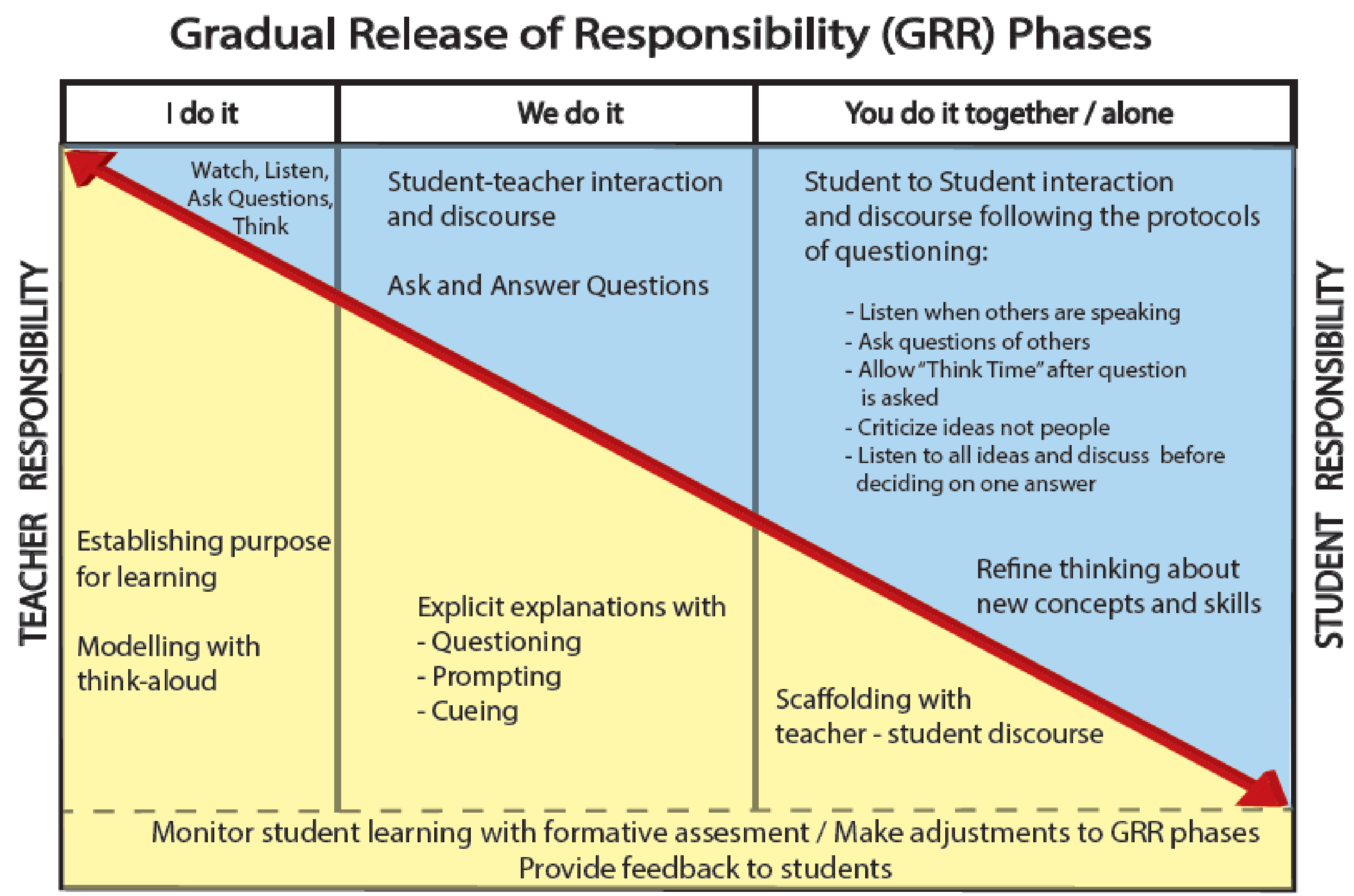


Figure 7.1 Modified GRR for teaching SIS

7.1 Limitations and further research

Based on the findings and observations made during the study, limitations and related areas of potential research include: (a) use of the GRR model for scaffolding Scientific Inquiry in another context; (b) use of a modified SOLO-taxonomy for evaluating aspects of scientific literacy; (c) application of the GRR model in a team teaching situation.

This study advanced previous findings such as those by Ireland et al. (2012) in proposing a pedagogical framework for structuring the classroom learning environment to scaffold student Scientific Inquiry. Ireland et al. (2012) highlighted the need for developing pedagogical practices that look beyond motivating students through interesting experiences, and beyond challenging them with teacher generated problems, to actually scaffolding students in the asking and answering of their own questions. Significantly, a modified GRR framework was instrumental in supporting students to develop aspects of the four categories of scientific literacy distilled from the literature. The findings revealed that a learning environment was established in which students engaged in rich conversations, designed and conducted experiments using fair testing procedures, made accurate observations and measurements, analysed and offered justifications for results, questioned the limitations of their ideas, and negotiated knowledge claims in ways similar to some of those in the scientific community. It is important to note that as a case study, findings cannot be generalised to other situations but can inspire others to explore the use of the GRR model in another context. Potential research may include other year levels. For example, how can the GRR model be used for teaching students in a lower year level such as Prep for scaffolding students in asking and answering of their own questions?

Furthermore, a modified SOLO-taxonomy rubric proved to be valuable for evaluating students' oral and written SIS outcomes. It is important to note that in this study the SIS Modified SOLO-taxonomy Rubric (Table 3.6) was developed and applied at the conclusion of instruction, however, it also has potential to play a role in formative assessment of students' responses throughout the teaching-learning cycle. The findings of this study may unlock various lines of inquiry and further research into the use of a modified SOLO-taxonomy for evaluating aspects of scientific literacy.

This study differentiates itself from previous studies in its analysis of both students' and teachers' language during science using a modified SOLO-taxonomy. Significantly, analysis of teacher-student dialogue using a modified SOLO-taxonomy revealed that the teacher's scaffolding with questioning, prompting and cueing facilitated an increase in students' demonstration of deeper level relational responses. In addressing the constraints raised in this study around time and differentiation, these results may be used to inform teacher coaching programs in which the GRR model might be applied in a team teaching situation. The partnership principles of instructional coaching may offer one way to expand upon the findings of this study by exploring how a collaborative approach using the phases of the GRR can support teachers to cater for the needs of students operating at different levels in a primary science class. Specifically, instructional coaches can help teachers to understand and use the modified SOLO-taxonomy as a tool for developing and asking questions. Likewise, if a coach was the main teacher and a novice or less confident teacher was part of the team, there might be a study in how the novice teacher develops confidence and competence in implementing the GRR for teaching SIS.

In conclusion, this study informs our theoretical understanding of the GRR model for implementing Science Inquiry. The GRR offered a flexible pedagogical approach for managing and modulating the information processing demands upon the teacher and learner (Driver, et al., 1994). The teacher in this case study modulated her teaching by repeating the phases of the GRR more than once in the lesson sequence. Furthermore, monitoring of students' conceptual understanding of science and application of Science Inquiry Skills were warranted so the phases of the GRR could be adjusted to accommodate the needs of students in developing foundational scientific literacy.

Fisher and Frey (2008) proposed there are four distinct instructional stages contained within the GRR model. These include focus lessons, guided instruction, collaborative learning, and independent tasks. However, in this study, the "You do it alone" phase as defined by Fisher and Frey was embedded within the "You do it together" phase, that is, students did not work solely on their own at any stage in this plant unit. The practical investigatory work that students undertook in science teams, which involved social interaction, provided a framework for individual students to refine their thinking about new concepts and skills (Norris & Phillips, 2003; Yore, et al., 2004). While science teams engaged in collaborative inquiry, each student recorded his or her thinking in a science journal, providing individual accountability. As a result of Stella's pedagogy using the GRR model, the students in this year-4 science class developed some cognitive and metacognitive abilities and Scientific Inquiry Skills (SIS) including strategies for questioning, discussing, reading and writing, evaluating scientific arguments and reasoning scientifically while engaged in processes of Scientific Inquiry (Yore et al., 2007).

Researchers and teacher educators can now work with this important contribution to our understanding to help practicing and pre-service primary school teachers to scaffold Science Inquiry Skills in the primary years.

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Appendix 1

Australian science curriculum year-4

Year-4 Level Description

The *Science Inquiry Skills* and *Science as a Human Endeavour* strands are described across a two-year band. In their planning, schools and teachers refer to the expectations outlined in the Achievement Standard and also to the content of the *Science Understanding* strand for the relevant year level to ensure that these two strands are addressed over the two-year period. The three strands of the curriculum are interrelated and their content is taught in an integrated way. The order and detail in which the content descriptions are organised into teaching/learning programs are decisions to be made by the teacher.

Australian Curriculum Content Descriptions

Science as a Human Endeavour	Science Inquiry Skills	Science Understanding
Nature and development of science • Science involves making predictions and describing patterns and relationships (ACSHE061) Use and influence of science • Science knowledge helps people to understand the effect of their actions (ACSHE062)	Communicating • Represent and communicate ideas and findings in a variety of ways such as diagrams, physical representations and simple reports (ACSIS071) Evaluating • Reflect on the investigation; including whether a test was fair or not (ACSIS069) Planning and conducting • Safely use appropriate materials, tools or equipment to make and record observations, using formal measurements and digital technologies as appropriate (ACSIS066) • Suggest ways to plan and conduct investigations to find answers to questions (ACSIS065)	Biological sciences • Living things have life cycles (ACSSU072) • Living things, including plants and animals, depend on each other and the environment to survive (ACSSU073)

Year-4 Achievement Standard

By the end of year-4, students apply the observable properties of materials to explain how objects and materials can be used. They use contact and non-contact forces to describe interactions between objects. They discuss how natural and human processes cause changes to the Earth's surface. They describe relationships that assist the survival of living things and sequence key stages in the life cycle of a plant or animal. They identify when science is used to ask questions and make predictions. They describe situations where science understanding can influence their own and others' actions.

Students follow instructions to identify investigable questions about familiar contexts and predict likely outcomes from investigations. They discuss ways to conduct investigations and safely use equipment to make and record observations. They use provided tables and simple column graphs to organise their data and identify patterns in data. Students suggest explanations for observations and compare their findings with their predictions. They suggest reasons why their methods were fair or not. They complete simple reports to communicate their methods and findings.

Appendix 2

Year-4 term 2 science pre-test

Name: ______________________ **Date:** ____________ **Class: 4A**

1. Draw and label 3 things plants needs to survive.

2. Draw and labels three things animals need to survive?

3. Explain what a life cycle is.

a. ____

b. ____

c. ____

4. In the boxes show the life cycle of a plant and an animal. You may choose any animal and plant you like.

Plant Life Cycle - _________________

Animal Life Cycle - _________________

Appendix 3

Student reflective journal example

9-5-14

Dear Diary,
This week in science we have been
learning about a life cycle of a bean
We also looked at what the bean looks like insi
We looked at a dry bean and a
soaked bean. ✓

The most interesting part of
science this week was watching
the chickens hatch and learnin
about a chicken's life cycle. I
also liked looking at the
seeds. ✓

The activity that I enjoyed
the most this week was the
bean life cycle because
long sentence
it was so interesting that
beans could grow up and
then drop the other beans
onto the ground so another

bean plant could grow.

I look forward to learning how the chickens grow up and I also look foward to making some TWLH charts in the future. ✓ ☺

16-5-14

Dear Diary,
This week in science we learnt about how a bean sprouts ~~and~~ grows.

I enjoyed learning about the beans because I liked how we got to plant our own bean seeds in a plastic cup. ✓

This week we talked about how to write a procedure. It must include a method. It was so fun!

Appendix 4

Student science inquiry skills survey

You have been learning to use Science Inquiry Skills during Science lessons.

Questioning – Asking and answering questions
Fair Test – Cows Moo Softly – Writing investigation questions
Observing – Making and recording observations
Measuring – Accurate and precise measurements
Analysing Data – Analysing, interpreting and recording data
Communicating – Using scientific language

How prepared or not prepared are you for doing your own experiment as a result of learning to use Science Inquiry Skills? (Circle your response)

Not at all prepared	A little bit prepared	Somewhat prepared	Quite a bit prepared	Very much prepared

How have these skills helped you to come up with an investigation question and do your own scientific experiment for Excellence Expo? (School Science Fair)

____

____

____

____

____

____

Appendix 5

Analysis of teacher's reflective journal

Sub-questions	Teacher's Reflective Journal - Data Collected
1. What strategies do teachers **use to implement GRR practices** in a year 4 Science class? ***1.Yellow: Modelling*** ***2.Aqua: Purpose explicit*** ***3.Pink: Determine students' understanding for further follow up*** ***4.Teacher explicitly taught SIS in You do and We do phases*** ***5.Students use SIS in collaborative science teams*** ***6.Posters are used as a reference to help teach SIS***	**Teacher's reflective journal** **Lesson 8 SIS Focus Analysing Data** I do: 1 **Model** 'fake' data first, then provide some scaffolding to support the whole class before allowing them to work in science teams. • **2Using a WALT** page on ppt to identify what we are learning. This is essential. The lesson is then finalized with the 'What we have learnt today' TWHL chart. All phases: 2 **Use of ICT** is the MOST effective strategy, particularly power points with I do, We do, You do in the corners to prompt students. This provides students with information about learning and expectations. **Lesson 6/7 SIS Focus Measuring** I do: • **Demonstrate** how students should take accurate measurements and record those measurements We do: • Gain some **knowledge of groups' ability** to complete tasks - determine who I need to follow up with and further review measuring activities

<table>
<tr>
<td>

Yellow: Modelling

Aqua: Purpose explicit

Pink: Determine students’ understanding for further follow up

Teacher explicitly taught SIS in You do and We do phases

Students use SIS in collaborative science teams</td>
<td>Lesson 5 SIS Focus Communicating

Not data from teacher

Lesson 4 SIS Focus Observing

We do:
This phase enabled students to learn how to observe and record their bean plant growth before working in science teams in ‘You do it together’
You do:
Students used observation skills learnt in the ‘We do’ phase
Lesson 2 SIS Focus Questioning

I do it:
I use the HPSS Science Inquiry Skills to explicitly teach the skills for questioning.
Posters of the skill displayed in the classroom to refer to has been an effective tool.
Watching me use the skills initially and then having a scaffolded approach to teaching the skills allows the students the opportunity to become more familiar with the skills before expected to work in a small group or alone.
We do it:
Working with small groups, the teacher can model questioning other students
Students who are more academically capable question other students, however less confident students don’t tend to ask questions.
Students were keen to participate in the ‘We do’ phase of GRR. They put up their hand and are engaged and interested in being part of this stage.
As students became more confident with their classmates, they are more willing to share their ideas and be challenged in front of the class.
You do it together:
Students love this stage – working together in a</td>
</tr>
</table>

Posters are used as a reference to help teach SIS *Challenges/constraints* ***Students' enthusiasm/interests***	small group. • **The challenge is how to get around to see all groups working and to ensure they are on the right track.** Generally I get stuck with groups that require more supervision or more assistance. • Ideally, this is the time to work with the higher ability groups to extend them. You do it alone: • **Students move from the 'You do it together' to 'You do it along' at different rates and this can be challenging**. Students who are more academically capable can move to the independent activities earlier where as some students will need more scaffolding and support in the earlier stage for a longer time. **This requires forethought and extensive planning.** **Lesson 1 SIS Focus Observing** I do it: • **Demonstration to observe** different parts of plants in the mystery box was used to make observations of each specific item in the box, as well **as 'self talk' to make links and connections** between plant items in the box. • In the engaging phase of the units 'Plants in Action', **it is imperative that students experience hands on tasks and a positive learning environment to engage and interest students.** Also, **making the context relevant to the students** and having the lesson based around a question seems to work to engage and raise the interest levels of students. • **During the engaging phase, and with the time constraints placed on science as 1.75hours per week, I find it very difficult to have students writing early observations.** We do it: • As a class, we constructed a bean plant life cycle on the whiteboard. Discussion involved reviewing the setting out of the life cycle ie clockwise direction, diagrams and labelling. Students were asked **to review poster from board and**

Yellow: Modelling *Aqua: Purpose explicit* *Pink: Determine students' understanding for further follow up* ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach SIS*** ***Challenges/constraints*** ***Students' enthusiasm/interests***	**consider prior knowledge and to make connections** between their knowledge of plants and life cycles. • We **identified what observable features** could be observed in plants. These ideas were written on the board - stem height, root growth, number of leaves and colour of stem and leaves. This activity was undertaken **demonstrating prior to students working in their science teams** to make observations about their 3 cups containing bean plants as part of their term investigation. You do it together: • **Students worked in their ability grouped science teams to make observations (orally only) about items in the mystery box. Working as a team, students were to make observations about individual items, as well as making connections of the items in the box. Students loved the opportunity to have a 'hands-on' task to complete, and the use of magnifying glasses (explicit teaching of use in Term 1) encouraged greater participation and more awareness of the intricacies of each item and their link to each other.** • **Students worked in their science team to make observations and identify similarities and differences between their bean plants in their investigation. They used observable features used in the 'We Do' phase of this activity listed on the board.**
2. What constraints/affordances does the teacher identify? *Yellow: Modelling* *Aqua: Purpose explicit* *Pink: Determine*	**Teacher's reflective journal** **Week 8 SIS Focus Analysing Data** • **Time is the biggest constraint. Allowing adequate time for this very important skill is extremely difficult. Most teachers are madly trying to complete work for the end of term or for assessment purposes, and particularly in science, struggle with not allowing ourselves enough time to give**

students' understanding for further follow up ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach SIS*** ***Challenges/constraints*** ***Students' enthusiasm/interests*** ***Yellow: Modelling***	**'Analysing Data' the time it deserves to be taught.** I do, We do • **Differentiation is a huge constraint. My lower achieving students would benefit from the 'I do' stage being taught at a lower level. Also repeating this lesson over 2 or 3 sessions would enable these students to have a more realistic understanding of their expectations.** You do it together: • **Assessing whose work it is – individual accountability in a group** You do it alone: • Time restraints teaching Data Analysis towards the end of a unit. Providing time to conference with individual students is a challenge. Yes – weekly discussions with teacher **Lesson 6/7 SIS Measuring** I do it: • **To ensure I was able to complete this stage of GRR I had to use additional time to teach the skill of measurement.** We do it: • This stage allows a review of prior knowledge and allows the teacher to feel more confident before allowing students to 'go it alone', however**, not all students demonstrate their skills in a group**. Ideally I would chose a less capable student from each group to

Aqua: Purpose explicit ***Pink: Determine students' understanding for further follow up*** ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach SIS*** *Challenges/constraints* ***Students' enthusiasm/interests***	demonstrate the 'We do' You do it together: • **Ensuring individual accountability. A system needs to be in place that all students take turns otherwise more confident students take over.** **Lesson 5 SIS Focus Communicating** We do it: • When preparing a scientific investigation together, through questioning and working together, I am able to have greater control over learning and **identify mistakes and misconceptions earlier than in the 'You do it together' stage**. You do it together: • **If I am working with another group I am not able to monitor all groups continually, and misconceptions/misunderstandings may not be identified and addressed immediately. This is particularly evident when there is a dominant group member that everyone follows. This needs to be monitored closely.** **Lesson 4 SIS Focus Observing** We do it: • I am able to **identify students' knowledge and understanding** of those students who raise their hands. I also direct questions to students without their hands raised to identify their knowledge and understanding. I use this formative assessment to guide future discussions in 'You do it' phase. • **Scientific language is used** so students can practice this language during 'You do it'

Yellow: Modelling *Aqua: Purpose explicit* *Pink: Determine students' understanding for further follow up* ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach SIS*** ***Challenges/constraints*** ***Students' enthusiasm/interests***	phase. You do it: • I encourage students to **use observable features discussed and noted on the board in the 'We do it' phase**. • I question groups to identify understanding of task and to ensure students are adequately differentiated. • The use of **scientific language is promoted in this phase as students put into practice** (in a supportive environment) new words learnt throughout the unit. • **I have to be careful using work produced in 'You do it' activity as assessment, as it could very well be another child's work and ideas simply being communicated in a child's book.** **Lesson 2 SIS Focus Observing** I do it: • **Interruptions such as phone calls, knocks on the door and behaviour interruptions can have a negative impact on any explicit teaching experience, but I find that when using 'I Do', I don't want any distractions or interruptions. I need all students engaged and focussed at this stage and ideally I don't want any equipment on tables eg magnifying glasses to distract them from concentrating on me.** • **Like all teachers, I am aware that we can talk too much, so finding the right balance of providing adequate information in a timely manner can be a fine line.** • **Sometimes, I am uncertain about students' prior knowledge** (if I haven't already pretested that specific area) and so wonder whether I need to spend the time using this strategy or go straight to the 'We Do'. **It is easier to start at the 'I Do' and then move forward quickly to 'We Do' rather than start at 'We Do' assuming prior knowledge and understanding and then have to go back.** • **With time constraints in our overcrowded**

Yellow: Modelling ***Aqua: Purpose explicit*** ***Pink: Determine students' understanding for further follow up*** ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach SIS*** ***Challenges/constraints*** ***Students' enthusiasm/interests***	**curriculum, it does take longer to use this strategy, although I firmly believe the long term effects outweigh the short term ones.** We do it: • **Some students are more confident and keen to participate in classroom discussions** and group activities and these students appear more engaged in this part of the lesson. If students are more engaged and they're participating, it is easier to gauge their understanding. Students who remain passive and fail to participate, provide a difficulty for me to make decisions about their abilities and understanding of the task. • I try to **move around the room to ensure everyone is participating** and demonstrating their understanding when the task involves some writing as well as oral discussion. You do it: • **Ensuring equal participation in groups can be challenging and requires the teacher to move around to all groups.** This can be difficult as some groups may be more 'needy' and require greater scaffolding and support. For eg, a low achieving group may need further assistance than a high ability group. **Lesson 1 SIS Focus Observing** I do it: • When using **'self talk' as part of this strategy**, I often feel quite foolish that I am saying aloud **my thoughts in my head (obviously censored to some degree).** • **Time is also a factor. By following this strategy, teachers need additional time to cover I Do, We Do, and You Do and this can create difficulties when attempting to complete the curriculum intent within a set time period.** • **Behaviour management can be an issue at this stage if students are not engaged in**

	the lesson • I actually love **this strategy as it provides a solid base for students to follow the task.** I feel that students don't require as make 'thinking time' or 'take up time' if they have first watched me undertake the task. **Particularly low achieving students benefit from this method**, as it provides them with more **scaffolding and enables me to more efficiently 'chunk' learning** eg I might say "Think about what was the first thing I did when I did the I Do? How might you do that? Show me." We do it: • I have a large range of abilities in the classroom, from A to E academically. Students also come from homes with varying opportunities and prior knowledge and experience**. During the 'We Do' stage, I expected all students to participate in the same content**, follow the same process, complete the same product and within the same environmental setting (Maker Model), where as I often wouldn't use this practice in my differentiated classroom**. The 'We Do' stage doesn't necessarily lend itself to differentiation in an explicit teaching lesson**. • As a 'We Do' activity, I am able to **identify students' knowledge and understanding** of those students who raise their hands. I also **direct questions to students who don't have their hand raised** in an **effort to identify students' knowledge and understanding** of the task. I am also able to guide future discussions in the 'You Do It Together' stage, by listing observable features on the board for each science team to discuss. The **use of scientific terminology and vocab i**s also used in this stage so that students can practice this language during the 'You Do It Together' phase. You do it:

	• I had wrongly assumed that students could complete a life cycle of a human as part of this method, after demonstrating a labelled diagram of a plant as part of the engagement phase. Working in teams, students got 'bogged' down on the reproductive processes of humans, rather than the actual task of completing a life cycle. I recognised this, stopped the group and moved on to the next task as a 'We Do' life cycle of a plant. It was originally anticipated that students would work alone to complete this life cycle.
What is positive about using GRR when teaching SIS? ***Yellow: Modelling*** ***Aqua: Purpose explicit*** ***Pink: Determine students' understanding for further follow up*** ***Teacher explicitly taught SIS in You do and We do phases*** ***Students use SIS in collaborative science teams*** ***Posters are used as a reference to help teach***	**Teacher's reflective journal** **Lesson 8 SIS Focus Data Analysis** I do • **Modeling** exactly what I am looking for. I can model exactly what I'm looking for in a discussion and conclusion, review data representation using table and graphs and be very specific about my thinking and identifying patterns and relationships of the results. We do together: • This stage can allow me the opportunity to **gauge students' understanding** of the concept I am teaching and to direct some of my questions to students who do not have their hands up. • By identifying groups who have less of an understanding of analyzing data, **I can direct myself or other resources to provide additional scaffolding.** You do it alone: • Gauge and **assess students'** individual achievements and **understanding of inquiry skills and scientific concepts.**

SIS ***Challenges/constraints*** ***Students' enthusiasm/interests***	**Lesson 6/7 SIS Focus Measuring** I do • Setting expectations for measuring accurately by **modeling.** We do • Provides **additional opportunity for students to watch and participate** before having to 'work together' as a group. You do it together: • **Students were able to demonstrate their knowledge and understanding of inquiry skill – measurement** **Lesson 5 SIS Focus Communicating** I do it: • Spending time **modeling** how to set up and complete a scientific investigation, students have an exemplar and expectations. We do it: • Students are provided with the opportunity to **review prior knowledge** from Term 1's science investigation. • I am able to **identify students' knowledge and understanding of investigation reporting** and identify which science teams may need greater assistance, eg., those groups that don't answer many questions or give incorrect answers. You do it together: • **Groups are more capable, higher academic performers can go ahead and complete tasks working collaboratively when completing communication tasks.**

	- I can chunk tasks and **give further scaffolding if required**. **Differentiation can be provided** – I can further extend more capable, higher achievers by giving them further scaffolding. **Students are able to discuss their investigation write up with students in their group before checking with the teacher.** **Lesson 4 SIS Focus Observing** You do it together: - Definitely students **using scientific terminology** modeled in the earlier stages. - Students have been **provided with a framework to guide their observations** to use as they discuss their plant growth with their peers. **Students are able to discuss their investigation write up in their group** before checking with teacher. Chances are at least one student in the group will be able to help out before asking the teacher for assistance. **Lesson 3 SIS Focus Questioning** I do it: **Modelling expectations for students is essential** and ensures students understand the task explicity. - I always worry that I talk too much (there is so much research to suggest that teachers do **TOO MUCH talking, so using a ppt can help to keep this in check.** - Having **specific protocols for questions on display in the classroom is great in science**, but quite honestly I find them even more useful when working with English and Maths (probably because more than half my week is taken up teaching these subjects).

	Referring to the protocols consistently allows students to build confidence and have a greater depth of understanding. - I continually **refer to the poster** as a reminder in the 'I do' phase and use the strategies of 'looks, feels, sounds like' often to help students understand. We do it: - This stage can **help gauge students' knowledge and understanding** and can assist with **differentiation**. You do it together: - This is **most students' preferred stage** as they like to work within a group when provided **adequate structure and scaffolding**. - In science I use *ability grouping* but this stage can be effective for lower students when non-ability group is utilized. **Lesson 2 SIS Focus Observing** I do it: - Explicit instructions can be given to **ensure students are aware of the expectations** of the task. We do it: - This strategy provides further **scaffolding and chunking for those students who may need additional assistance** with a task and require more support before working independently. You do it together: **Students enjoy working in a group, and so this stage provides a 'safe' place for students to work and be challenged in their group. Students enjoy this stage and enjoy the discussions and social interactions that go with it. Learning from each other's mistakes at this stage can be very positive!**

	Lesson 1 SIS Focus Observing I do it: • The best part of using this strategy is that **students are explicitly taught exactly how to complete the observation and record their observations**. Students have a greater understanding of my expectations, and this strategy catered for different learning styles • **Students need to be very familiar with this strategy (GRR)** to understand how the lesson is progressing. We use GRR in English, Maths, Science, History, Geography and The Arts, and students have become familiar with the posters on the wall as well as the names of the strategies and the teacher/ student roles which coincide with them. We do it: • Using the 'We Do' strategy **effectively reinforced 'I Do'** and my explicit instructions of setting out and completion of tasks. For all students, but more noticably for students who require chunking and scaffolding, the 'We Do' stage offers reinforcement of the process to complete a specific task, and also **offers students the opportunity to have the task broken down into chunks** to further understanding. **You do it together:** • **This task reinforced those students who had a solid understanding/ mastery of the skill to create a life cycle of a human. It is especially important for students who are not confident to work alone to have the opportunity to work within a small group and share ideas. As my science teams are ability grouped**, the science team consisting of low C/D students require additional support/ scaffolding from teacher but this **does allow more able students to work independently and go ahead** (considering Maker Model of Differentiation).

3. What outcomes do students achieve?	**Teacher's reflective journal** **Lesson 8 SIS Focus Data Analysis** • Students are independently seeking scientific words from the word wall to complete their scientific reports. • They are asking for less help and are more independent in groups • They generally engage in group discussions when I move to a new group • Breaking each lesson up into focusing on a particular skill this term rather than just teaching the lessons without an inquiry skill focus has been a great addition to my teaching repertoire. If I can identify with WALT, the importance of data analysis, for example, and then explicitly teach that skill referring to posters, students develop a knowledge base of each skill and they can better identify throughout the scientific report which skills they have used and they can refer to the posters for more information and guidance. **Lesson 6/7 SIS Focus Measurement** • Students are able to identify the units of measurement to measure a plant • Students are able to make accurate measurements of a stem length • Students are able to identify ways to check that their measurements are accurate, eg., estimation, having another student check same answer. • Record accurate measurements in a table • Students were able to complete graphs with limited assistance and start to discuss relationships and patterns between their data. • I was impressed with the students' level of confidence graphing. • This skill is also taught in mathematics.

	Lesson 5 SIS Focus Communicating • Students were able to complete the first section of their investigation, i.e., aim, hypothesis, materials, fair testing procedures and procedure in science teams. • Differentiation was offered to science teams based on the support required. • Students were guided to use scientific vocabulary with correct spelling • Students used a template to create a plan of their investigation. • Students were more independent completing their investigation because the task had been modeled previously. **Lesson 4 SIS Focus Observing** • Students are increasingly using scientific terminology learnt in the unit. • In differentiated science teams there is an identifiable difference between the levels of conversations when observing plants and making inferences about why things are happening. It is like seeing their brains 'light up' when they get it! • At this stage our observations are only verbal as they make comparisons and hypothesize why their plants are growing differently! **Lesson 2 SIS Focus Questioning** • Students working in small groups are certainly expanding their knowledge and are willing to listen to others in their group and their ideas. • It was interesting to note that a few students who initially though seeds were non-living, were converted after only 3 minutes of discussion in the 'We do it' phase'. • More confident and academically able students were observed asking questions of their peers to clarify information. **Lesson 1 SIS Focus Observing**

	• This lesson was an engaging lesson, with the **goal to engage students in learning and to provide a platform from which to explore** 'Plants in Action'. • Students were able to identify the significant features of a plant i.e., leaf, flower, stem and roots, which was later transferred into a labelled diagram 'We Do' on the whiteboard. • Using magnifying glasses, students were able to identify more intricate parts of the leaf eg hairs on the fern leaf. • **Students were able to ask questions of each other** about the source of plant and its parts and links/ connections were made between seed pods, for example, and predictions made as to how seeds might have been dispersed and where they might be now. • The senses of touch and sight were used extensively during the mystery box activity. Some groups also chose to smell some of the plant parts and make links with their prior knowledge. • Students were able to use their prior knowledge of plants to use descriptions about the items in the mystery box e.g., stem, leaves, roots, hair, flower.

Appendix 6

Lesson analysis with GRR model

LESSON 1: SIS Focus Observing – observing plants and drawing a labelled diagram

Questioning – about basic needs of plants

Phase	**I do time**	**We do time**	**You do together time**	**You do it alone time**	**Focus**
I do	8 mins				Purpose of lesson explicit: WALT TWHL chart – discuss ideas and questions to add to the chart. Word Wall – create a list of words that relate to plants and animals.
I do	2 mins				Teacher modelling how to observe plant parts.
We do/You do it together		5 mins			Students observing plants.
We do it		5 mins			Teacher questions to discover what students know about the basic needs of plants.

I do it	2 mins			Teacher modelling observing and drawing a labelled diagram of a plants.
We do it/I do it		8 mins		How to draw a labelled diagram of a plant Teacher modelling how to draw a labelled diagram.
You do it			9 mins	Draw a life cycle of a human. **STOP AND RETEACH**
We do it		8 mins		Draw a life cycle of a plant. TWHL chart – update with new learning.
Total	12 mins	26 mins	9 mins	

LESSON 2: SIS Focus Observing/Questioning

I do it We do it	4 mins	1min		Warm-up to engage students. Teacher think aloud observing novel picture.
I do it	2 mins			Purpose of lesson explicit – WALT TWHL chart – revise prior learning.
We do it		1 min		Warm-up engaging students observing novel pictures.
I do it	4			Think aloud teacher observing

	mins				and describing a banana.
We do it		4 mins			Teacher explains protocols for questioning and then uses them questioning, prompting, cueing students. Students practise asking and answering questions about a bean seed picture with teacher support.
We do it/ I do it/ You do it together		15 mins			Observing a dry bean seed. Includes teacher think aloud to demonstrate how to draw a shape. Teacher encourages scientific language as students work in science teams together.
You do it together			7 mins		Observing practise – a wet bean seed.
We do it		3 mins			Update word wall – students share all the new words they have learnt. TWHL chart – update with new learning.
TOTAL	10 mins	21 mins	18 mins	0 mins	

LESSON 3 SIS Focus Observing and Questioning

I do it	6 mins		Teacher explains why they are learning about germinating bean seeds and explicitly explained the purpose of the lesson – WALT. TWHL chart – revise prior learning.
I do it	2 mins		Observing novel pictures warm-up. Teacher questioning students.
We do it		3 mins	Questions asked to promote discussion were written on the power point. Bean Seeds • Why are beans kept in a waterproof packet? What are the effects of water on the seeds? Observing seeds and packet.
We do it with I do it * *Good example of flexibility*	3 mins	15 mins	Bean seed germination procedure is presented on ppt. and explained. Students are guided step by step to set up the investigation with ***'I do'*** demonstration by teacher. Fair testing procedure

You do it together			11 mins	Set up investigation as a group following the procedure on power point.
We do it		7 mins		Teacher continues to explicitly guide students to begin their Bean Seed Germination Timeline. Observe and record results
We do it		3 mins		TWHL Chart – update with new learning. Word wall – update with new words.
Total	11 mins	28 mins	11 mins	

LESSON 4 SIS FOCUS Observing and Fair test

I do it	1 min			Clearly states the purpose of lesson and identifies this on the Lesson ppt. as WALT. TWHL chart – revise prior learning.
I do it	5 mins			T revisits 'Observation' SIS throughout the phase. T refers to poster and uses a ppt.

We do it		10 mins		Teacher revises observation as a SIS (referring to poster) and how to do a fair test using Cows Moo Softly
You do it together			6 mins	**Cows Moo Softly** is listed on ppt. Teacher guides group discussion of the process one step at a time so that Science Teams can discuss if they doing a fair test accurately.
We do it		5 mins		Communicating skills Teacher explicitly teaches how to communicate with scientific vocabulary
You do it together			9 mins	Observe and record growth of plant on "Timeline". Students work in science teams.
You do it together			8 mins	Students make observations of their bean plants in science teams. They discuss and make comparisons between the stem of the plant, the colours of the stem and leaves, root growth and the number of leaves.
Total	6 mins	15 mins	23 mins	

LESSON 5 SIS FOCUS Analysing Data and Communicating

I do it	4 mins		Purpose of lesson made explicit with teacher lead discussion. Communicating in science.
We do it	3 mins		Teacher refers to **students' interests** about "Deadly Animals" as a focus for reading and interpreting data.
We do it	6 mins		Communicating Accurately Reflect on students' previous explanations in Science Journals to analyse for accuracy and precision.
We do it	6 mins		Explicit explanation of how to do an annotated diagram. Teacher refers to ppt. list on Annotated Diagrams. (See below for transcript).
You do it together		27 mins	Students work in science teams to record observations of plant growth in an annotated diagram.
We do it	5 mins		Teacher guides whole class to think of words for the class word wall and reflect on WALT. TWHL chart – update with new learning.

Total	4 mins	20 mins	27 mins	

LESSON 6 SIS FOCUS Measuring and Recording Data, Communicating

I do	1 min			Clearly states the purpose of lesson and identifies this on the Lesson power point as WALT. TWHL chart – revise prior learning.
We do it **combined** with You do it together		5 mins	2 mins	THINK, PAIR, SHARE: Students use this strategy to discuss their opinion about the question in science team and as a whole class, "Measuring accurately makes out data more reliable".
We do it **combined** with I do it think aloud	1 min	3 mins		Explicit teaching of Measuring SIS. Teacher refers to power point slide with question,
I do it	5 mins			Teacher models how to label plants for investigation. Teacher clearly states the

				purpose of lesson section.
We do it		11 mins		Teacher guides students as teams collect equipment and set up to label first plant as demonstrated in ‘I do’.
You do it together			7 mins	Teacher monitors groups as they remove plants from cups and label them.
I do it	4 mins			T models how to measure plants accurately and how to record results. T Clearly states the purpose of lesson section.
We do it		2 mins		Teacher guides students to practise recording measurement data in a table.
You do it together Stopped and retaught how to **DRAW** a table		6 mins	1 min	Students draw a table to record bean seed investigation results. Students work in science teams. Students did not DRAW the table properly in their books so teacher stopped the You do it and reverted to We do it.
Total	11 mins	27 mins	10 mins	

LESSON 7 Observing, Measuring, Communicating

We do it including purpose of lesson explicit.	1 min	7 mins		Teacher guides students to measure their first bean plant together. They measure and record their results in a table.
You do it together			45 mins	Students make observations of their bean plants in science teams. They measure and record their results in a table and using photography.
We do it		6 mins		Teacher leads whole class discussion to update TWHL chart and word wall.
Total	1 min	13 mins	45 mins	

LESSON 8 SIS FOCUS Communicating

I do it	2 mins			Clearly states the purpose of lesson and identifies this on the Lesson ppt. as WALT. TWLH chart – revise prior learning.

We do it **combined** with You do it together		5 mins	2 mins	Teacher elicits students' existing understandings about 'Analysing data' then explicitly describes in detail what it means. Teacher refers to Analysing Data poster and uses a ppt. THINK, PAIR, SHARE to answer the question: 'What does analysing data mean?'
I do it	2 mins			Teacher revisits 'Analysing Data' SIS. T refers to Analysing Data poster and uses a ppt. to demonstrate how to represent data in a graph.
We do it		3 mins		Teacher asked for volunteer to analyse data from a graph on ppt.
I do it	2 mins			Teacher demonstration of analysing data on a graph to construct a discussion. Teacher reads aloud her own discussion.
We do it		6 mins		Guided instruction on how to analyse results to write a discussion.
You do it			17 mins	Teacher circulates to monitor

together				groups. She demonstrates and helps students with **questioning and prompting** to record observations of bean seed growth as an annotated diagram. Particular emphasis is placed on developing academic language.
I do it	6 mins			Teacher demonstrates how to write a conclusion.
You do it together			2 mins	Teacher circulates to monitor groups. She demonstrates and helps students with **questioning and prompting** to write a conclusion of bean seed investigation. Particular emphasis is placed on developing scientific language. Students needed another 30 mins to complete on the following day.
We do it		3 mins		TWHL chart – update with new learning.
Total	12	13	21 mins	

Appendix 7

Analysis of student learning outcomes with the modified SOLO taxonomy example

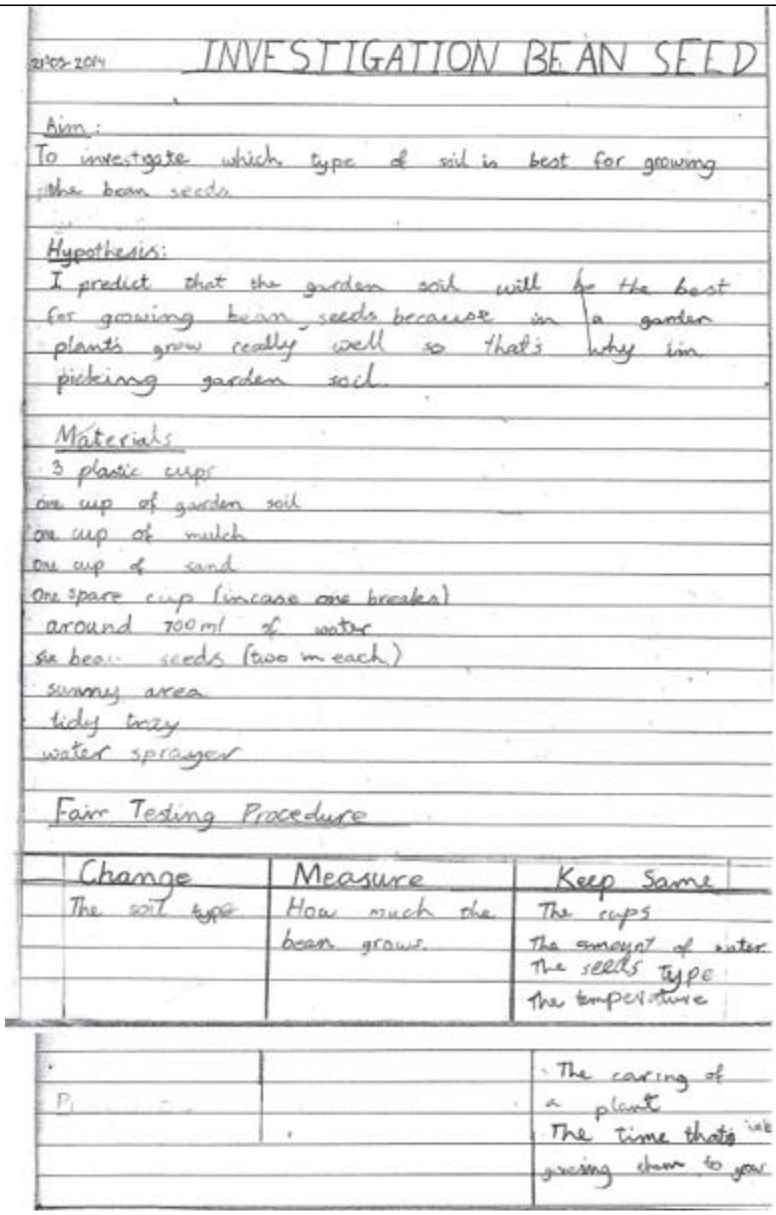
Analysis of the quality of one student's written outcomes in this study using the SIS Modified SOLO-taxonomy.

R5: Communicates with scientific vocabulary to explain aim of investigation.

R5: Makes a prediction; Explains possible reason for prediction.

M3: Lists materials; Provides details.

M4: Lists variables that are changed, measured and kept the same.



21-05-2014 INVESTIGATION BEAN SEED

Aim:
To investigate which type of soil is best for growing the bean seeds

Hypothesis:
I predict that the garden soil will be the best for growing bean seeds because in a garden plants grow really well so that's why im picking garden soil.

Materials
3 plastic cups
one cup of garden soil
one cup of mulch
one cup of sand
One spare cup (incase one breaks)
around 700 ml of water
six bean seeds (two in each)
sunny area
tidy tray
water sprayer

Fair Testing Procedure

Change	Measure	Keep Same
The soil type	How much the bean grows.	The cups The amount of water The seeds type the temperature The caring of a plant The time that we are giving them to grow

6

Analysis of a discussion by the science team “Queensland” of the question, “Measuring accurately makes our data more reliable”.

Peter	Ok, yes it does. You can actually remember it, if you record. So say you can’t just measure it once. You can’t say, ‘Eliza was measuring hers’. She, you know how we like take care of our own plant and we each measure our own and say, ‘This is this’. Each needs to measure each one so then we accurately record it and then discuss it. (R5: Explains how measuring accurately makes the data more reliable)
Polly	You’ve got to go over it again. (U2: Responds to a question; Mentions a procedure)
Peter	You’ve got to go over it and over it and double check. (M4: Builds on another students’ ideas; Explains reasoning)
Stella	What do you think that statement means then?
Peter	By accurately, yea, and that makes it more accurate because you’ve measured it multiple times. And that will be recorded in your data, which means if you were to come along like a minute later and you had nothing and recorded it, it would probably be about the same as what we had. (R5: Explains reasons for accurate scientific measurements)
Polly	So, like you have to double check. (U2: Comments on a procedure for measuring)

(Teacher then guided a whole class discussion to share ideas)

Stella	Great job. I was really impressed to come around and listen to people who were just talking about this. I was really impressed, well done. Measuring accurately makes our data more reliable, who would like to share what their group talked about, what their group said? Peter.
Peter	You can’t just measure it once and trust just what somebody else

says. You need to come again and measure it then measure it multiple times so it's more accurate. So if somebody else was to come along in a few minutes and do the same they will probably get the same data as you. (R5: Explains reasons for accurate scientific measurements)

Stella — Ok, so from that you're telling me that today each member of your group today is going to do the same measurements to check. Ok, is that right? (Peter nods) Ok, great idea.

Fran — If it's not accurate it's not a fair test. (R5: Explains reason for accurate scientific measurements)

Stella — Alright, can you explain a little bit more?

Fran — Like if we just measured, if we measured it and then we forgot the measurements and just thought of something and just randomly wrote that down it wouldn't be accurate measurements because it wouldn't be the same as what we previously measured. (R5: Responds to a question; Explains ideas for accurate scientific measurements)

Appendix 8

Science inquiry skills in the year-4 science unit

Year-4 Science Unit	
Lesson 1 SIS Focus	WALT:
What goes where?	• BIG IDEA – 'How Does Time Affect Me?'
Observing	• recall the basic needs of living things.
	• represent stages in the life cycle of flowering plants
ENGAGE	• label parts of a plant: root, stem, leaves, flowers, fruit.
	• discuss ideas and questions for a TWLH chart
	• create a list of words that relate to plants and animals
Lesson 2 SIS Focus	WALT:
What's in a seed?	• What have we learnt so far? Review TWHL Chart
Questioning	• Using the skill of Questioning to discover what we know about seeds
	• Use 'We Do' strategy to record observations of a dry bean seed
EXPLORE	• Use 'You Do' strategy to record observations of a soaked bean seed
	• label a diagram of the inside of a bean
	• Update TWLH Chart
	• Review word wall
Lesson 3 SIS Focus	WALT:
Bean seed germination	• BIG IDEA – 'How Does Time Affect Me?'
Observing and Questioning	• explore packaged bean seeds
	• read and discuss a procedural text for a bean seed germination activity
EXPLORE	• work in teams to prepare bean seeds
	• make ongoing observations and recordings of bean seed germination
	• Review TWHLchart
Lesson 4 SIS Focus	WALT:

Observing, Investigating and Communicating EXPLORE	• Review TWHL chart • Review Observation skills • Make observations of bean seed growth • Review Investigation Procedures • Review Communication skills • Review word wall
Lesson 5 SIS Focus Making sense of communicating in science EXPLAIN	WALT: • Review Communicating in Science • Making Observations • How does sunlight affect plant growth? • How do soil types affect plant growth? • How does temperature affect plant growth? • Review TWHL chart • Review Word Wall
Lessons 6 & 7 SIS Focus Measuring in science ELABORATE	WALT: • Review measuring in science • Review ways of recording measurements • Fair testing and measuring • Make and record measurements • Review TWHL chart • Review word wall
Lesson 8 SIS Focus Analysing data in science EVALUATE	WALT: • Review investigation • Discuss results of investigation from each group • Consider ways of analysing data in science • Record in science journals • Review TWHL chart

Appendix 9

Structure of eight lessons

LESSON 1: SIS Focus Observing – observing plants and drawing a labelled diagram Questioning – about basic needs of plants					
Phase	**I do time**	**We do time**	**You do together time**	**You do it alone time**	**Focus**
I do	8 mins				Purpose of lesson explicit: WALT TWHL chart – discuss ideas and questions to add to the chart. Word Wall – create a list of words that relate to plants and animals.
I do	2 mins				Teacher modelling how to observe plant parts.
We do/You do it together		5 mins			Students observing plants.
We do it		5 mins			Teacher questions to discover what students know about the basic needs of plants.
I do it	2 mins				Teacher modelling observing and drawing a labelled diagram of a plants.
We do it/I do it		8 mins			How to draw a labelled diagram of a plant Teacher modelling how to draw a labelled diagram.
You do it			9 mins		Draw a life cycle of a human. **STOP AND RETEACH**
We do it		8 mins			Draw a life cycle of a plant. TWHL chart – update with new learning.
Total	12 mins	26 mins	9 mins		

LESSON 2: SIS Focus Observing/Questioning

I do it We do it	4 mins	1min			Warm-up to engage students. Teacher think aloud observing novel picture.
I do it	2 mins				Purpose of lesson explicit – WALT TWHL chart – revise prior learning.
We do it		1 min			Warm-up engaging students observing novel pictures.
I do it	4 mins				Think aloud teacher observing and describing a banana.
We do it		4 mins			Teacher explains protocols for questioning and then uses them questioning, prompting, cueing students. Students practise asking and answering questions about a bean seed picture with teacher support.
We do it/ I do it/ You do it together		15 mins			Observing a dry bean seed. Includes teacher think aloud to demonstrate how to draw a shape. Teacher encourages scientific language as students work in science teams together.
You do it together			7 mins		Observing practise – a wet bean seed.
We do it		3 mins			Update word wall – students share all the new words they have learnt. TWHL chart – update with new learning.
TOTAL	10 mins	21 mins	18 mins	0 mins	

LESSON 3 SIS Focus Observing and Questioning

I do it	6 mins				Teacher explains why they are learning about germinating bean seeds and explicitly explained the purpose of the lesson – WALT. TWHL chart – revise prior learning.
I do it	2 mins				Observing novel pictures warm-up. Teacher questioning students.
We do it		3 mins			Questions asked to promote discussion were written on the power point. Bean Seeds Why are beans kept in a waterproof packet?

				What are the effects of water on the seeds? Observing seeds and packet.
We do it with I do it ** Good example of flexibility*	3 mins	15 mins		Bean seed germination procedure is presented on ppt. and explained. Students are guided step by step to set up the investigation with ***'I do'*** demonstration by teacher. Fair testing procedure
You do it together			11 mins	Set up investigation as a group following the procedure on power point.
We do it		7 mins		Teacher continues to explicitly guide students to begin their Bean Seed Germination Timeline. Observe and record results
We do it		3 mins		TWHL Chart – update with new learning. Word wall – update with new words.
Total	11 mins	28 mins	11 mins	

LESSON 4 SIS FOCUS Observing and Fair test

I do it	1 min			Clearly states the purpose of lesson and identifies this on the Lesson ppt. as WALT. TWHL chart – revise prior learning.
I do it	5 mins			T revisits 'Observation' SIS throughout the phase. T refers to poster and uses a ppt.
We do it		10 mins		Teacher revises observation as a SIS (referring to poster) and how to do a fair test using Cows Moo Softly
You do it together			6 mins	**Cows Moo Softly** is listed on ppt. Teacher guides group discussion of the process one step at a time so that Science Teams can discuss if they doing a fair test accurately.
We do it		5 mins		Communicating skills Teacher explicitly teaches how to communicate with scientific vocabulary
You do it together			9 mins	Observe and record growth of plant on "Timeline". Students work in science teams.
You do it together			8 mins	Students make observations of their bean plants in science teams. They discuss and

				make comparisons between the stem of the plant, the colours of the stem and leaves, root growth and the number of leaves.
Total	6 mins	15 mins	23 mins	

LESSON 5 SIS FOCUS Analysing Data and Communicating

I do it	4 mins			Purpose of lesson made explicit with teacher lead discussion. Communicating in science.
We do it		3 mins		Teacher refers to **students' interests** about "Deadly Animals" as a focus for reading and interpreting data.
We do it		6 mins		Communicating Accurately Reflect on students' previous explanations in Science Journals to analyse for accuracy and precision.
We do it		6 mins		Explicit explanation of how to do an annotated diagram. Teacher refers to ppt. list on Annotated Diagrams. (See below for transcript).
You do it together			27 mins	Students work in science teams to record observations of plant growth in an annotated diagram.
We do it		5 mins		Teacher guides whole class to think of words for the class word wall and reflect on WALT. TWHL chart – update with new learning.
Total	4 mins	20 mins	27 mins	

LESSON 6 SIS FOCUS Measuring and Recording Data, Communicating

I do	1 min			Clearly states the purpose of lesson and identifies this on the Lesson power point as WALT. TWHL chart – revise prior learning.
We do it **combined** with You do it together		5 mins	2 mins	THINK, PAIR, SHARE: Students use this strategy to discuss their opinion about the question in science team and as a whole class, “Measuring accurately makes out data more reliable”.
We do it **combined** with I do it think aloud	1 min	3 mins		Explicit teaching of Measuring SIS. Teacher refers to power point slide with question,
I do it	5 mins			Teacher models how to label plants for investigation. Teacher clearly states the purpose of lesson section.
We do it		11 mins		Teacher guides students as teams collect equipment and set up to label first plant as demonstrated in ‘I do’.
You do it together			7 mins	Teacher monitors groups as they remove plants from cups and label them.
I do it	4 mins			T models how to measure plants accurately and how to record results. T Clearly states the purpose of lesson section.
We do it		2 mins		Teacher guides students to practise recording measurement data in a table.
You do it together Stopped and retaught how to **DRAW** a table		6 mins	1 min	Students draw a table to record bean seed investigation results. Students work in science teams. Students did not DRAW the table properly in their books so teacher stopped the You do it and reverted to We do it.
Total	11 mins	27 mins	10 mins	

LESSON 7 Observing, Measuring, Communicating

We do it including purpose of lesson explicit.	1 min	7 mins		Teacher guides students to measure their first bean plant together. They measure and record their results in a table.
You do it together			45 mins	Students make observations of their bean plants in science teams. They measure and record their results in a table and using photography.
We do it		6 mins		Teacher leads whole class discussion to update TWHL chart and word wall.
Total	1 min	13 mins	45 mins	

LESSON 8 SIS FOCUS Communicating

I do it	2 mins			Clearly states the purpose of lesson and identifies this on the Lesson ppt. as WALT. TWLH chart – revise prior learning.
We do it **combined** with You do it together		5 mins	2 mins	Teacher elicits students' existing understandings about 'Analysing data' then explicitly describes in detail what it means. Teacher refers to Analysing Data poster and uses a ppt. THINK, PAIR, SHARE to answer the question: 'What does analysing data mean?'
I do it	2 mins			Teacher revisits 'Analysing Data' SIS. T refers to Analysing Data poster and uses a ppt. to demonstrate how to represent data in a graph.
We do it		3 mins		Teacher asked for volunteer to analyse data from a graph on ppt.
I do it	2 mins			Teacher demonstration of analysing data on a graph to construct a discussion. Teacher reads aloud her own discussion.
We do it		6 mins		Guided instruction on how to analyse results to write a discussion.
You do it together			17 mins	Teacher circulates to monitor groups. She demonstrates and helps students with **questioning and prompting** to record observations of bean seed growth as an annotated diagram. Particular emphasis is placed on developing academic language.
I do it	6 mins			Teacher demonstrates writing a conclusion.
You do it together			2 mins	Teacher circulates to monitor groups. She demonstrates and helps students with **questioning and prompting** to write a conclusion of bean seed investigation. Particular emphasis is placed on developing scientific language. Students needed another 30 mins to complete on the following day.
We do it		3 mins		TWHL chart – update with new learning.
Total	12 mins	13 mins	21 mins	

Appendix 10

Teacher affordance categories

Affordance categories generated by the qualitative analysis

First level category	Second level category and its implications for student outcomes	Statements from teacher's reflective journal
The phases of the GRR provided opportunities for the teacher to explicitly teach SIS and scaffold students in the "I do it" and "We do it" phases.	Expectations were communicated. (Students had an understanding of expectations)	Demonstration to observe different parts of plants in the mystery box was used to make observations of each specific item in the box, as well as 'self talk' to make links and connections between plant items in the box. (L1, Observing, "I do it") I use the school Science Inquiry Skills [a framework developed in the science coaching trial breaking skills down into key teaching points] to explicitly teach the skills for questioning. (L2, Questioning, "I do it") Explicit instructions can be given to ensure students are aware of the expectations of the task. (L2, Observing, "I do it") Using the "We do it" strategy effectively reinforced "I do it" and my explicit instructions of setting out and completion of tasks. For all students, but more noticeably for students who require chunking and scaffolding, the "We do it" phase offers reinforcement of the process to complete a

specific task, and also offers students the opportunity to have the task broken down into chunks to further understanding.
(L 3, Observing, “We do it”)

The best part of using this strategy is that students are explicitly taught exactly how to complete the observation and record their observations. Students have a greater understanding of my expectations, and this strategy catered for different learning styles.
(L1, Observing, “I do it”)

We identified what observable features could be observed in plants. These ideas were written on the board – stem, height, root growth, number of leaves and colour of stem and leaves. This activity was undertaken demonstrating prior to students working in their science teams to make observations about their 3 cups containing bean plants as part of their term investigation.
(L1, Observing, “We do it”)

I actually love this strategy as it provides a solid base for students to follow the task. I feel that students don't require as make 'thinking time' or 'take up time' if they have first watched me undertake the task. Particularly low achieving students benefit from this method, as it provides them with more scaffolding and enables me to more efficiently 'chunk' learning e.g. I might say "Think about what was the first thing I did when I did the I Do? How might you do that? Show me.
(L1, Observing, “I do it)
Modelling expectations for students is essential and ensures students understand the task explicitly.

	(L3, Questioning, “I do it”) Spending time modelling how to set up and complete a scientific investigation, students have an exemplar and expectations. (L5, Communicating, “I do it”) Demonstrate how students should take accurate measurements and record those measurements. (L6, Measuring, “I do it”) Setting expectations for measuring accurately by modelling. (L7, Measuring, “We do it”) Modelling exactly what I am looking for. I can model exactly what I’m looking for in a discussion and conclusion, review data representation using table and graphs and be very specific about my thinking and identifying patterns and relationships of the results. (L8, Analysing Data, “I do it”) Using a WALT page on Powerpoint to identify what we are learning. This is essential. The lesson is then finalised with the ‘What we have learnt today’ TWHL chart. (L8, Analysing data, “I do it”) Model ‘fake’ data first, then provide some scaffolding to support the whole class before allowing them to work in science teams. (L8, Analysing Data, “I do it”) Breaking each lesson up into focusing on a particular skill this term rather than just teaching

		the lessons without an inquiry skill focus has been a great addition to my teaching repertoire. If I can identify with WALT, the importance of data analysis, for example, and then explicitly teach that skill referring to posters, students develop a knowledge base of each skill and they can better identify throughout the scientific report, which skills they have used and they can refer to the posters for more information and guidance. (L8, Analysing Data, "I do it")
	Scientific vocabulary was promoted and practised. (Students developed an understanding of scientific vocabulary)	The use of scientific language is promoted in this phase as students put into practice (in a supportive environment) new words learnt throughout the unit. (L1, Observing, "We do it") Scientific language is used so students can practise this language during "You do it" phase. (L4, Observing, "We do it")
	Science Inquiry Skills were scaffolded (Students were able to practise SIS with scaffolding)	As a class, we constructed a bean plant life cycle on the whiteboard. Discussion involved reviewing the setting out of the life cycle, i.e., clockwise direction, diagrams and labelling. Students were asked to review poster from board and consider prior knowledge and to make connections between their knowledge of plants and life cycles. (L1, Observing, "We do it") Students were keen to participate in the "We do it" phase of GRR. They put up their hand and are engaged and interested in being part of this stage. (L2, Questioning, "We do it") As students became more confident with their

		classmates they are more willing to share their ideas and be challenged in front of the class. (L2, Questioning, “We do it”) Watching me use the skills initially and then having a scaffolded approach to teaching the skills allows the students the opportunity to become more familiar with the skills before expected to work in small group or alone. (L2, Questioning, “I do it”) It was interesting to note that a few students who initially thought seeds were non-living, were converted after only 3 minutes of discussion in the ‘We do it’ phase’. (L2, Questioning, “We do it”) This phase enabled students to learn how to observe and record their bean plant growth before working in science teams in “You do it together”. (L4, Observing, “We do it”) Students are provided with opportunity to review prior knowledge from term one’s science investigation. (L5, Communicating, “We do it”) Provides additional opportunity for students to watch and participate before having to “work together” as a group. (L6, Measuring, “We do it”)
	Cues were used to reinforce all the important aspects of each skill.	Students need to be very familiar with this strategy (GRR) to understand how the lesson is progressing. We use GRR in English, Maths, Science, History, Geography and The Arts, and students have become familiar with the posters

	on the wall as well as the names of the strategies and the teacher/ student roles, which coincide with them. (L1, Observing, "I do it") Use of ICT is the MOST effective strategy, particularly power points with "I do it", "We do it", "You do it" in the corners to prompt students. This provides students with information about learning and expectations (L2, Questioning, "I do it") Posters of the skills displayed in the classroom to refer to has been an effective tool. (L2, Questioning, "I do it") Having specific protocols for questions on display in the classroom is great in science, but quite honestly I find them even more useful when working with English and Maths (probably because more than half my week is taken up teaching these subjects). (L3, Questioning, "I do it") Referring to the protocols consistently allows students to build confidence and have a greater depth of understanding. (L3, Questioning, "I do it") I continually refer to the poster as a reminder in the 'I do' phase and use the strategies of 'looks, feels, sounds like' often to help students understand. (L3, Questioning, "I do it") I encourage students to use observable features discussed and noted on the board in the "We do

		it" phase. (L4, Observing, "You do it together")
The teacher's formative assessment in the "I do it" and "We do it" phases enabled the teacher to determine students' understanding for further follow-up in all phases.	Science teams were ability grouped. (Students worked at their own rate in science teams)	I have a large range of abilities in the classroom, from A to E academically. Students also come from homes with varying opportunities and prior knowledge and experience. During the 'We Do' stage, I expected all students to participate in the same content, follow the same process, complete the same product and within the same environmental setting (Maker Model), where as I often wouldn't use this practice in my differentiated classroom. (L1, Observing, "We do it") Students move from the "You do it together" to 'You do it along' at different rates and this can be challenging. Students who are more academically capable can move to the independent activities earlier where as some students will need more scaffolding and support in the earlier stage for a longer time. This requires forethought and extensive planning. (L2, Questioning, "You do it alone") In differentiated science teams there is an identifiable difference between the levels of conversations when observing plants and making inferences about why things are happening. It is like seeing their brains 'light up' when they get it! (L4, Observing, "You do it together") Differentiation was offered to science teams based on the support required. (L5, Measuring, "You do it together")

	Teacher worked with students and science teams who required more scaffolding. (Students demonstrated SIS with scaffolding)	Ideally, this is the time to work with the higher ability groups to extend them. (L2, Questioning, “You do it”) Working with small groups, the teacher can model questioning other students. (L2, Questioning, “We do it”) This strategy provides further scaffolding and chunking for those students who may need additional assistance with a task and require more support before working independently. (L2, Observing, “We do it”) Differentiation can be provided – I can further extend more capable, higher achievers by giving them further scaffolding. (L5, Communicating, “You do it together”) I can chunk tasks and give further scaffolding if required. (L5, Communicating, “You do it together”)
	Teacher monitored students’ learning. (Students were monitored to identify mistakes, misconceptions and participation)	I had wrongly assumed that students could complete a life cycle of a human as part of this method, after demonstrating a labelled diagram of a plant as part of the engagement phase. Working in teams, students got 'bogged' down on the reproductive processes of humans, rather than the actual task of completing a life cycle. I recognised this, stopped the group and moved on to the next task as a 'We Do' life cycle of a plant. It was originally anticipated that students would work alone to complete this life cycle. (L1, Observing, “You do it together”) The challenge is how to get around to see all

groups working and to ensure they are on the right track. Generally, I get stuck with groups that require more supervision or more assistance.
(L2, Questioning, “You do it”)

Sometimes, I am uncertain about students’ prior knowledge (if I haven’t already pretested that specific area) and so wonder whether I need to spend the time using this strategy or go straight to the “We do it”. It is easier to start at the “I do it” then move forward quickly to “We do it” rather than start at “We do it” assuming prior knowledge and understanding and then have to go back.
(L2, Observing, “I do it”)

Some students are more confident and keen to participate in classroom discussions and group activities and these students appear more engaged in this part of the lesson. If students are more engaged and they're participating, it is easier to gauge their understanding. Students who remain passive and fail to participate, provide a difficulty for me to make decisions about their abilities and understanding of the task.
(L2, Observing, “We do it”)

This stage can help gauge students’ knowledge and understanding and can assist with differentiation.
(L3, Questioning, “We do it”)

I question groups to identify understanding of task and to ensure students are adequately differentiated.
(L4, Observing, “You do it together”)

I am able to identify students’ knowledge and

understanding of those students who raise their hands. I also direct questions to students without their hands raised to identify their knowledge and understanding. I use this formative assessment to guide future discussions in “You do it together”.
(L4, Communicating, “We do it”)

When preparing a scientific investigation together, through questioning and working together, I am able to have a greater control over learning and identify mistakes and misconceptions earlier than in the “You do it together” phase.
(L5, Communicating, “We do it”)

I am able to identify students’ knowledge and understanding of investigation reporting and identify which science teams may need greater assistance, e.g., those groups that don’t answer many questions or give incorrect answers.
(L5, Communicating, “We do it”)

“We do it” phase allows me to gain some knowledge of groups’ ability to complete tasks – determine who I need to follow up with and further review measuring activities.
(L6, Measuring, “We do it”)

This phase allows a review of prior knowledge and allows the teacher to feel more confident before allowing students to “go it alone”, however, not all students demonstrate their skills in a group. Ideally, I would chose a less capable student from each group to demonstrate the “We do it”.
(L6, Measuring, “We do it”)

This phase can allow me the opportunity to gauge

		students' understanding of the concept I am teaching and to direct some of my questions to students who do not have their hands up. (L8, Analysing Data, "We do it") Gauge and assess students' individual achievements and understanding of inquiry skills and scientific concepts. (L8, Analysing Data, "You do it alone")
The teacher's scaffolding in the "I do it" and "We do it" phases enabled students to use SIS in the "You do it together" phase in differentiated science teams.	Students demonstrated their knowledge and understanding of SIS when working in science teams.	Students worked in their ability grouped science teams to make observations (orally only) about items in the mystery box. Working as a team, students were able to make observations about individual items, as well as making connections of the items in the box. Students loved the opportunity to have a "hand-on" task to complete, and the use of magnifying glasses (explicit teaching of use in Term 1) encouraged greater participation and more awareness of the intricacies of each item and their link to each other. (L1, Observing, "You do it together" within "We do it") The senses of touch and sight were used extensively during the mystery box activity. Some groups also chose to smell some of the plant parts and make links with their prior knowledge. (L1, Observing, "You do it together" within "We do it") Students were able to use their prior knowledge of plants to use descriptions about the items in the mystery box e.g. stem, leaves, roots, hair, flower. (L1, Observing, "You do it together" within "We do it")

Students worked in their science team to make observations and identify similarities and differences between their bean plants in their investigation. They used observable features used in the “We do it” phase of this activity listed on the board.
(L4, Observing, “You do it together)

Students used observation skills learnt in the “We do it” phase. At this stage our observations are only verbal as they make comparisons and hypothesize why their plants are growing differently!
(L4, Observing, “You do it together”)

Students were able to complete the first section of their investigation, i.e., aim, hypothesis, materials, fair testing procedures and procedure in science teams.
(L5, Measuring, “You do it together”)

Students used a template to create a plan of their investigation and were more independent completing their investigation because the task had been modelled previously.
(L5, Communicating, “You do it together”)

Students were able to demonstrate their knowledge and understanding of inquiry skill measurement.
(L6, Measuring, “You do it together”)

Students are able to identify units of measurement to measure a plant.
(L6, Measuring, “You do it together”)

		Students are able to identify ways to check that their measurements are accurate, e.g. estimation, having another student check same answer. (L6, Measuring, “You do it together”) Students are able to make accurate measurements of a stem length and record accurate measurements in a table. (L6, Measuring, “You do it together”) Students were able to complete graphs with limited assistance and start to discuss relationships and patterns between their data. (L7, Measuring, “You do it together”) I was impressed with the students’ level of confidence in graphing. This skill is also taught in mathematics. (L7, Measuring, “You do it together”)
	Students worked at their own pace in differentiated science teams.	As my science teams are ability grouped, the science team consisting of low C/D students require additional support/ scaffolding from teacher but this does allow more able students to work independently and go ahead (considering Maker Model of Differentiation). (L1, Observing, “You do it together”) Groups are more capable, higher academic performers can go ahead and complete tasks working collaboratively when completing communication tasks. (L5, Communicating, “You do it together”)
	Science teams provided a supportive and collaborative learning	In the engaging phase of the unit, “Plants in Action”, it is imperative that students experience hands on tasks and a positive learning environment to engage and interest students. Also, making the context relevant to the students

	environment for students to engage in student-student dialogue.	and having the lesson based around a question seems to work to engage and raise interests of students. (L1, Observing, “We do it”) Students were able to ask questions of each other about the source of plant and its parts and links/ connections were made between seed pods, for example, and predictions made as to how seeds might have been dispersed and where they might be now. (L1, Observing, “You do it” within We do it”) This task reinforced those students who had a solid understanding/ mastery of the skill to create a life cycle of a human. It is especially important for students who are not confident to work alone, to have the opportunity to work within a small group and share ideas. (L1, Observing, “You do it together”) Students love this stage – working together in small group. (L2, Questioning, “You do it together”) Students enjoy working in a group, and so this phase provides a “safe” place for students to work and be challenged in their group. Students enjoy this phase and enjoy the discussions and social interactions that go with it. Learning from each other’s mistakes at this stage can be very positive. (L2, Observing, “You do it together) Students working in small groups are certainly expanding their knowledge and are willing to listen to others in their group and their ideas.

		(L2, Observing, "You do it together) More confident and academically able students were observed asking questions of their peers to clarify information. (L2, Questioning, "You do it together) This is most students' preferred stage as they like to work within a group when provided adequate structure and scaffolding. (L3, Questioning, "You do it together") In science I use ability grouping but this stage can be effective for lower students when non-ability group is utilised. (L3, Questioning, "You do it together") Students have been provided with a framework to guide their observations to use as they discuss their plant growth with peers. (L4, Observing, "You do it together) Students are able to discuss their investigation write up with students in their group before checking with the teacher. Chances are at least one student in the group will be able to help out before asking the teacher for assistance. (L5, Communicating, "You do it together") They are asking for less help and are more independent in groups. (L8, Analysing Data, "You do it together")
	Students used scientific vocabulary modelled in	The use of scientific language is promoted in this phase as students put into practice (in a supportive environment) new words learnt in the unit. (L4, Observing, "You do it together")

	previous stages.	
		Students were guided to use scientific vocabulary with correct spelling. (L5, Measuring, “You do it together”) Definitely students using scientific terminology modelled in earlier phases. (L4, Observing, “You do it together”) Students are increasingly using scientific terminology learnt in the unit. (L4, Observing, “You do it together”) Students are independently seeking scientific words from the word wall to complete their scientific reports. (L8, Analysing Data, “You do it together”)

Note: The source number constitutes: Lesson number, SIS focus for lesson, Phase of GRR

Appendix 11

Teacher constraint categories

Constraints identified by the case study teacher in her reflective journal	**Category**
The challenge is how to get around to see all groups working and to ensure they are on the right track.	Student accountability
Assessing whose work it is – individual accountability in a group.	Student accountability
Yes – weekly discussions with teacher.	Student accountability
Behaviour management can be an issue at this stage if students are not engaged in the lesson.	Student accountability
Ensuring individual accountability. A system needs to be in place that all students take turns otherwise more confident students take over.	Student accountability
I have to be careful using work produced in 'You do it together' activity as assessment, as it could very well be another child's work and ideas simply being communicated in a child's book.	Student accountability
Ensuring equal participation in groups can be challenging and requires the teacher to move around to all groups.	Student accountability
During the engaging phase, and with the time constraints placed on science as 1.75 hours per week, I find it very difficult to have students writing early observations.	Time
Time is the biggest constraint. Allowing adequate time for this very important skill is extremely difficult. Most teachers are madly trying to complete work for the end of term or for assessment purposes, and particularly in science, struggle with not allowing ourselves enough time to give 'Analysing Data' the time it deserves to be taught.	Time
Time restraints teaching Data Analysis towards the end of a unit. Providing time to conference with individual students is a challenge.	Time
To ensure I was able to complete this stage of GRR I had to use additional time to teach the skill of measurement.	Time
With time constraints in our overcrowded curriculum, it does take longer to use this strategy, although I firmly believe the long term effects outweigh the short term ones.	Time

Time is also a factor. By following this strategy, teachers need additional time to cover I Do, We Do, and You Do and this can create difficulties when attempting to complete the curriculum intent within a set time period.	Time
Students move from the ‘You do it together’ to ‘You do it along’ at different rates and this can be challenging.	Differentiation
Differentiation is a huge constraint. My lower achieving students would benefit from the ‘I do’ stage being taught at a lower level. Also repeating this lesson over 2 or 3 sessions would enable these students to have a more realistic understanding of their expectations.	Differentiation
Differentiation is a huge constraint. My lower achieving students would benefit from the ‘I do’ stage being taught at a lower level. Also repeating this lesson over 2 or 3 sessions would enable these students to have a more realistic understanding of their expectations.	Differentiation
I always worry that I talk too much (there is so much research to suggest that teachers do TOO MUCH talking, so using a PowerPoint can help to keep this in check.	Teacher talk
Like all teachers, I am aware that we can talk too much, so finding the right balance of providing adequate information in a timely manner can be a fine line.	Teacher talk